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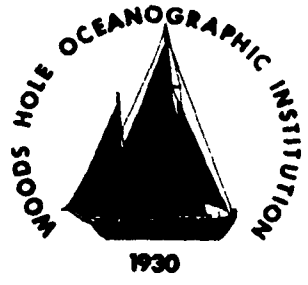
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*Arthur E. Maxwell*

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PREFACE

Members of the research staff of the Institution have for many years prepared an annual summary of their investigations. For the first decade or so of the Institution's history these were appended to The Annual Report. As the Institution grew, these contributions also became of such size it was impractical to continue appending them to the Annual Report and a separate *Summary of Investigations* was circulated. Now, after thirteen issues of the *Summary of Investigations* we are attempting to provide similar information in a somewhat different format.

In this volume, we have collected abstracts of all papers that have been submitted for publication by the staff of the Institution during the calendar year 1975. In particular, we have included a section containing the theses and abstracts of students' work and a section with abstracts of papers submitted by our Marine Policy and Ocean Management Programs. Since some of these papers may not be published in the journal to which they have been submitted initially, we have intentionally omitted identifying the journals. This has been done in order to avoid later confusion should the article eventually be published elsewhere. The volume is not intended to be a bibliography.

The purpose of this collection of abstracts is to provide the reader with timely and concise information on research activities recently completed within the Institution. Although not as detailed as the *Collected Reprints* of the Institution, the material herein is more comprehensive and available considerably in advance. Further, it is intended to supplement the more limited information about our scientific activities contained within the Institution's *Annual Report*.

The abstracts have been included, as far as possible, without editorial change, as submitted by the Department Chairman and the Dean of Graduate Studies.

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*Arthur E. Howell*

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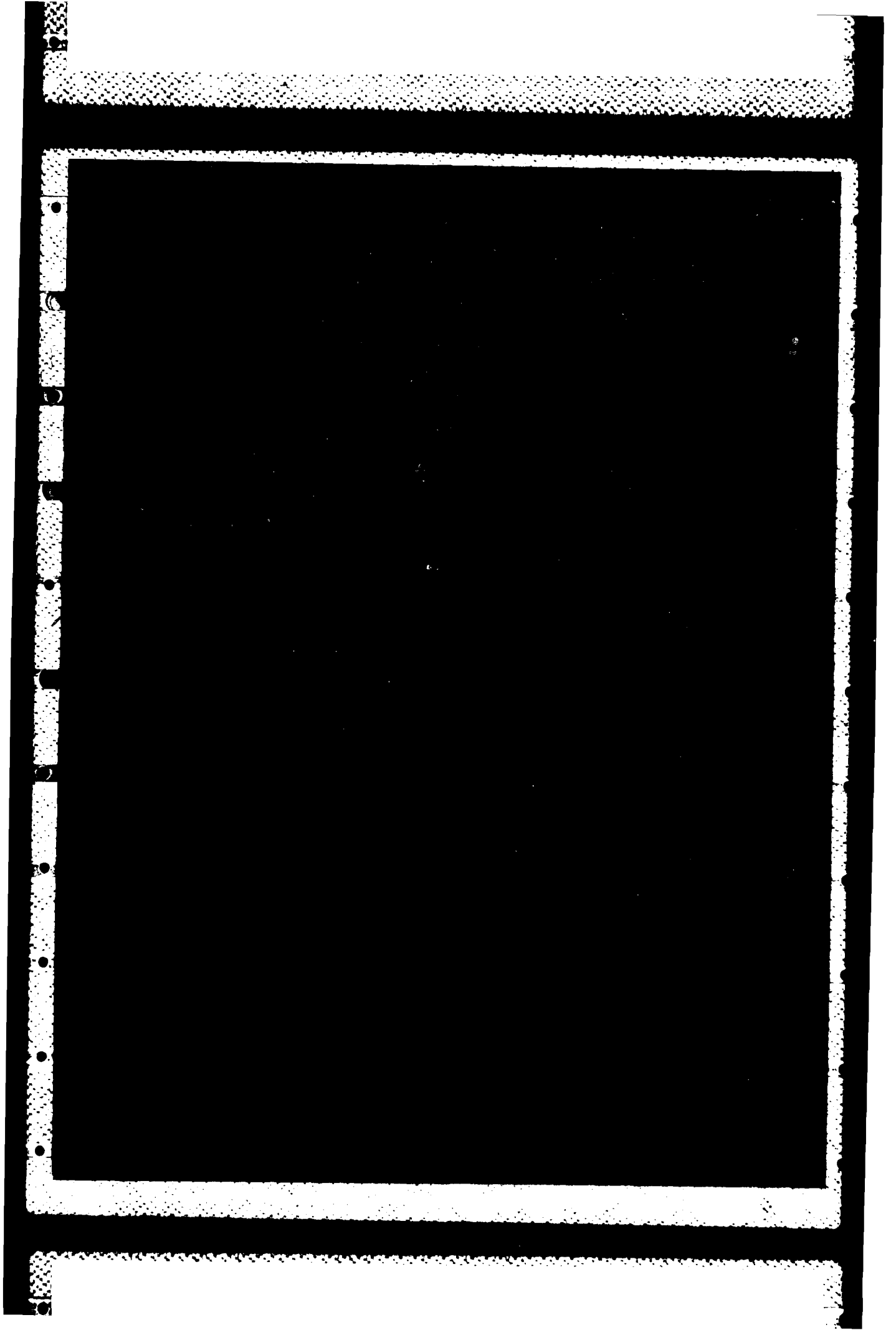
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Fisheries Regulation: Variations on a Theme Leah J. Smith and Susan B. Peterson (Supported by Office of Sea Grant, Dept. of Commerce, Grant No. 14-6-158-44016)	MP-6
The Economics of Waste Water-Aquaculture Systems Leah J. Smith and John E. Huguenin (Supported by Office of Sea Grant, Dept. of Commerce, Grant No. 04-5-158-1(MIT) and 04-5-158-8 (WHOI))	MP-7
Technological Transfer in Marine Science Leah J. Smith and David A. Ross (see GG-35 for abstract)	MP-7





DEPARTMENT OF BIOLOGY

George D. Grice, Department Chairman

## MICROBIOLOGY

## A NEW CONCEPT IN POWER PLANT OPERATION TO CONTROL SLIME BACTERIA IN STEAM ELECTRIC CONDENSER COOLING SYSTEMS

Milton R. Anderson, Ralph C. Vaccaro and Richard C. Tonner

The paper describes the investigations in identification and control of the fouling organisms - commonly referred to as "slime" - that grow in the condenser tubes at Brayton Point Power Station in Somerset, Massachusetts. Oxygen utilization, gross identification, bacteriological counts, elementary composition and temperature survival experiments in the laboratory were performed in the "slime" organisms isolated from the condenser system. The experiments suggest that bacteria are a major component of the slime biomass and can withstand temperatures in liquid culture ranging between 56°C (132.8°F) and 59°C (138.2°F).

A series of tests were performed in the condensers of the power plant for the purpose of controlling "slime" growth. This involves a power plant operational mode that dewateres one-half of the condenser and "cooks" the slime. A temperature of 54.4°C (130.0°F) sustained for a period of two hours was most effective of the tests performed for reducing the number of "slime" organisms in the condenser tubes. The effects of this method of control of "slime" as related to improvement of power plant efficiency needs further investigation.

Published in: *Proceedings of the workshop held at Johns Hopkins University. Technology & Ecological Effects of Biofouling Control Procedures of Thermal Power Plant Cooling Water Systems - Ecological Analysis Inc. 1975.*

Supported by: *New England Electric System.*

## INFLUENCE OF SUBSTRATE WETTABILITY ON THE ATTACHMENT OF MARINE BACTERIA TO VARIOUS SURFACES

Stephen C. Dexter, James D. Sullivan, Jr., Albert J. Williams, III, and Stanley W. Watson. Collaborators: Bostwick H. Ketchum and Herbert Uhlig.

The effect of the initial substrate surface condition, as indicated by the critical surface tension for wetting, on the rate of attachment of marine bacteria to a variety of solid surfaces has been measured. The techniques used to determine the number of bacteria attached per unit surface area were a lipopolysaccharide test utilizing *Limulus* lysate and direct examination of the surface by scanning electron microscopy. The results obtained by the two techniques are compared and their significance to the control of microbiological slime film formation (microfouling) is discussed.

Published in: *Applied Microbiology.*

Supported by: *Alcoa Foundation and U.S. Energy Research Development Administration E(11-1)-3565.*

## METHANE OXIDATION IN LAKE KIVU (CENTRAL AFRICA)

Holgar W. Jannasch

The rate of methane oxidation in Lake Kivu is estimated at  $0.48 \text{ mmoles m}^{-3}\text{day}^{-1}$  or  $1.16 \times 10^8 \text{ m}^3 \text{ yr}^{-1}$  for the whole lake as measured in a layer of 15 m thickness above the oxic/anoxic interface. A total volume of  $50 \text{ km}^3$  of methane is calculated to be contained in the lake, the rates of methane production and of methane consumption appear to be of the same order of magnitude. The vertical diffusion of methane, and thereby its oxidation upon reaching the oxic surface waters, is strongly restricted by the thermohaline stratification of the lake.

Published in: *Limnology and Oceanography*. 1975.

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LIMULUS LYSATE TEST FOR GRAM-NEGATIVE BACTERIAL MENINGITIS:  
BEDSIDE APPLICATION

Sydney Ross, MD; William Rodriguez, MD; Guido Controni, MS; George Korengoid, MD; Stanley Watson, PhD; Waheed Khan, PhD.

The limulus lysate assay on cerebrospinal fluid was evaluated in 335 infants and children as a method for the rapid diagnosis of Gram-negative bacterial meningitis. Positive limulus tests were obtained within one hour in 33 of 34 cases of *Hemophilus influenzae* meningitis; four additional patients with Gram-negative meningitis also showed positive limulus lysate tests. Conversely, 13 patients with Gram-positive bacterial meningitis all yielded negative limulus assays. All 48 cases of aseptic meningitis and 236 children with no meningitis showed negative limulus assays. Antibiotic therapy prior to hospitalization did not vitiate the validity of the test. A bedside adaptation of the limulus test, performed by house officers and medical students, showed approximately 98% agreement with the laboratory assay.

Published in: *Journal of the American Medical Association*. 1975.

Supported by: *The Arthur Vining Davis Foundation*.

## ENDOTOXINS: THE LIMULUS AMOEOCYTE LYSATE SYSTEM

James D. Sullivan, Jr., Frederica W. Valois, Stanley W. Watson

Limulus amoebocyte lysate (LAL) is an aqueous extract of blood cells (amoebocytes) from the horseshoe crab *Limulus polyphemus*. LAL forms a firm clot when incubated with endotoxins at  $37^\circ\text{C}$ . LAL is currently employed to detect and quantify endotoxins in a variety of solutions and this technique is commonly referred to as the LAL test.

Although there have been numerous publications dealing with the LAL test there is no general agreement concerning the use of this test, its specificity or the reliability of the LAL test. In this chapter the authors will review most of the pertinent literature dealing with the LAL test, will present new data concerning the test, and will evaluate this test in light of the current state of knowledge.

Published in: *Mechanisms in Bacterial Toxinology*, A. Bernheimer (ed.), John Wiley and Sons, Inc. 1975.

Supported by: *Arthur Vining Davis Foundation and Atomic Energy Commission E(11-1)-3565.*

*FACTORS AFFECTING THE SENSITIVITY OF LIMULUS LYSATE*

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

Limulus lysate clots when mixed with picogram quantities of endotoxins. The sensitivity of the lysate was improved 100-fold by the removal of an inhibitor and addition of divalent cations. The methods developed in this investigation eliminated much of the seasonable variability of the lysate, improved the heat stability after lyophilization, and made it possible to use the lysate with saline solutions.

Published in: *Applied Microbiology*. 1975.

Supported by: *Whitehall Foundation.*

*PURIFICATION AND PROPERTIES OF THE CLOTTING ENZYME FROM LIMULUS LYSATE*

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

The clotting enzyme from limulus lysate which is involved in the gelation reaction of lysate with endotoxin has been purified and some of its properties determined. It was isolated from endotoxin-treated lysate and purified by gel filtration, ion exchange chromatography, and disc gel electrophoresis. Reaction of clotting enzyme with lysate clottable protein produces a clot or gel such as occurs with the gelation of lysate by endotoxin. Purified clotting enzyme has an approximate molecular weight of 84,000 (subunit MW 43,000), is isoelectric at pH ca. 5.5, trypsin-like, heat labile and pH sensitive.

Published in: *Biochemical and Biophysical Research Communications*. 1975.

Supported by: *Arthur Vining Davis Foundation.*

*INHIBITORY EFFECT OF HEPARIN ON THE LIMULUS TEST FOR ENDOTOXIN*

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

Heparin can inhibit the Limulus test for endotoxin unless 0.05 M CaCl<sub>2</sub> and 0.154 M NaCl are added to the lysate.

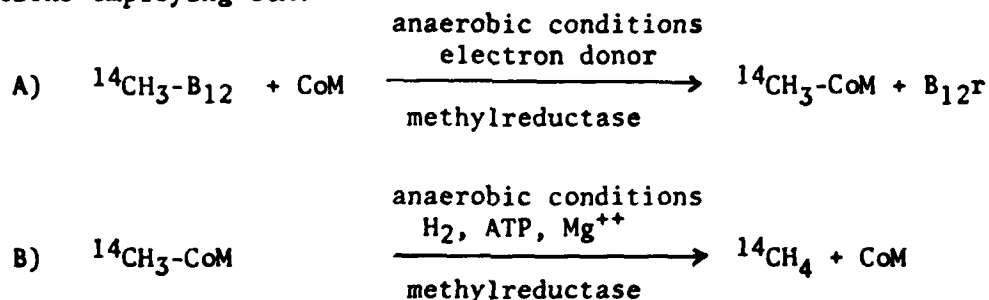
Published in: *Journal of Clinical Microbiology*. 1975.

Supported by: *Arthur Vining Davis Foundation.*

ISOLATION AND IDENTIFICATION OF A NEW COFACTOR  
(COENZYME M) IN METHYL TRANSFER REACTIONS

Craig D. Taylor. Collaborator: Ralph S. Wolfe

Coenzyme M (CoM) is a recently discovered cofactor which is involved in the methyl transfer reactions in *Methanobacterium* (*Biochem. 10: 2317 (1971); J. Biol. Chem. 249: 4886 (1974)*). Methane production from methylcobalamin proceeds via two enzymic reactions employing CoM:



Reaction B, catalyzed by methylreductase, is specifically inhibited by tripolyphosphate and measurement of the radioactivity trapped in (methyl-<sup>14</sup>C) CoM serves as an assay for CoM. CoM was purified by extraction into methanol, anion exchange chromatography, gel filtration chromatography, continuous electrophoresis, and crystallization from acetone-water. The information derived from infrared, proton NMR, and ultraviolet spectroscopy as well as from chemical tests and quantitative elemental analysis reveals that CoM is 2,2'-dithiodiethanesulfonic acid.

Evidence indicates that the active form of this cofactor is 2-mercaptoethanesulfonic acid which is methylated producing 2-(methylthio)ethanesulfonic acid. This derivative is subsequently reductively demethylated, yielding methane.

In press: "Akademie der Wissenschaften".

Supported by: *National Science Foundation Grants GB-27681 and GB-37626X*

MICROBIAL UTILIZATION OF THIOSULFATE IN THE DEEP SEA

Jon H. Tuttle and Holger W. Jannasch. Assistance: Steven Molyneaux.

Natural microbial populations in deep and shallow North Atlantic water and previously isolated heterotrophic thiosulfate-oxidizing bacteria have the potential to metabolize thiosulfate when incubated *in situ* at elevated hydrostatic pressure and low temperature.

Supported by: *National Science Foundation Grants GB-29665 and DES75-15017.*

*REDUCTIVE TRANSFORMATIONS OF INORGANIC SULFUR BY  
A FACULTATIVELY ANAEROBIC MARINE BACTERIUM*

Jon H. Tuttle and Holger W. Jannasch

The kinetics of formation of inorganic sulfur products during anaerobic growth of a facultatively anaerobic marine pseudomonad, utilizing a variety of inorganic sulfur compounds as electron acceptors, was investigated. Results suggested the following conversions: i) quantitative tetrathionate reduction to thiosulfate; ii) trithionate reduction to equimolar sulfite and thiosulfate; iii) sulfite reduction to thiosulfate through trithionate; and iv) thiosulfate reduction to sulfide and trace sulfite. Comparisons of growth rates and cell yields at various initial combinations of electron donors and acceptors indicated that tetrathionate and thiosulfate were the electron acceptors of choice, and that the sulfur transformations were true dissimilatory reductions. The pathways of inorganic sulfur metabolism were unaffected by the organic electron donor used. The reactions described are similar to transformations carried out by the obligately anaerobic sulfate-reducing bacteria of the genera *Desulfovibrio* and *Desulfotomaculum* as well as certain species of the *Enterobacteriaceae*. The widespread occurrence of these facultatively anaerobic bacteria at oxygen-sulfide interfaces in anoxic marine basins, in inshore waters, and in sediments may imply a cycling of inorganic sulfur compounds without the formation of sulfate.

Published in: *Bacteriological Proceedings*. 1975.

Supported by: *National Science Foundation Grants GA-29665 and DES75-15017*.

*RESPONSE OF NATURAL MARINE BACTERIAL POPULATIONS TO COPPER:  
A CONTROLLED ECOSYSTEM POLLUTION EXPERIMENT*

Ralph F. Vaccaro, Farooq Azam and Robert E. Hodson  
Collaborator: Pamela Bowman

Additions of  $\text{Cu}^{2+}$  at low concentrations (10 and 50 parts per billion) to two intact marine ecosystems led to a marked increase in relative numbers and activity of bacterial heterotrophs. This phenomenon was apparently triggered by the release of available organic carbon from one or more components of the ecosystem when subjected to Cu stress. Apparently, heterotrophic bacteria which demonstrated an increased tolerance to Cu with time played an important role in the rapid mineralization of stress-produced organic substances thereby affecting succeeding phytoplankton regimes.

Supported by: *I.D.O.E. office of the National Science Foundation under research grants GX 39147*.

*THE EFFECT OF SUSPENDED PARTICLES ON THE GROWTH OF MARINE BACTERIA  
IN CONTINUOUS CULTURE*

Carl O. Wirsen and Holger W. Jannasch

Continuous culture techniques have been employed to detect growth responses of marine bacterial isolates to the type, concentration and size of suspended organic and inorganic particles. Steady state cultures receiving an injection of

clay particles demonstrated a marked increase in cell density or in the incorporation of  $^{14}\text{C}$ -labeled glutamate (approx.  $\frac{1}{2}\log$ ). Populations would slowly return to the initial steady state level as the particles were washed out. Bentonite exhibited a stronger stimulation than kaolinite. Growth of non-chitin-degrading bacterial isolates was increased by an addition of homogenized and washed chitin particles to glutamate limited cultures. When chemostats being supplied with media devoid of particles were shifted to media containing bentonite, higher steady state populations were measured with most isolates. Short term perturbations have been noted in chemostat cultures shifted to media containing ashed offshore sediment, exemplified by a rapid decline in cell density followed by the establishment of the original steady state level. Suspended particulate matter in offshore waters may afford a growth advantage to organisms living under conditions of substrate limitation. It is probable that direct attachment to particles is not required for gaining this advantage.

Published in: *Bacteriological Proceedings*, 1975.

Supported by: *National Science Foundation Grants GA 29665 and DES75-15017.*

#### THE DECOMPOSITION OF SOLID ORGANIC MATERIALS IN THE DEEP-SEA

Carl O. Wirsen and Holger W. Jannasch

Samples of solid organic materials (various seaweeds and woods, paper, chitin, fish meat, food stuffs, etc.), incubated for up to 15 months in the deep sea at depths of 1830 to 5300 meters, degraded at markedly reduced rates as compared to those of controls incubated in shallow water or in the laboratory at equal temperatures. Similar results were obtained in more refined experiments with solidified agar, starch, and gelatin placed at defined positions above, below, and at the sediment surface by the research submersible *ALVIN*. Removal of these materials by invertebrate feeding appeared to exceed the rate of degradation by microorganisms at the northern station (continental slope off Nantucket), but not at the southern station (Tongue of the Ocean, Bahamas). In connection with other results it appears that a population of free-living (non-intestinal) microorganisms specifically adapted to deep-sea conditions does not exist.

Supported by: *National Science Foundation Grants GA 33405, DES75-15017, and OCE75-21278.*

#### ACTIVITY OF MARINE PSYCHROPHILIC BACTERIA AT ELEVATED HYDROSTATIC PRESSURES AND LOW TEMPERATURES

Carl O. Wirsen, Holger W. Jannasch

Uptake and metabolic turnover of a variety of radioactively labeled substrates by a number of bacterial isolates from several depths in offshore Atlantic waters were studied in laboratory experiments. The variable conditions were hydrostatic pressure (1 to 400 atm), temperature ( $1.5^{\circ}$  to  $15.0^{\circ}\text{C}$ ), concentration of substrate (2 to  $500\ \mu\text{g/ml}$ ), and time of incubation (4 h to 8 weeks). Elevated hydrostatic pressure and low temperature retarded the rate of metabolism (biosynthesis more than respiration) in all isolates tested, but considerably less in those of psychrophilic character.

Published in: *Marine Biology*. 1975.

Supported by: *National Science Foundation Grants GA 33405 and GA 29665.*



## PHYTOPLANKTON

## ALKALINITY CHANGES GENERATED BY PHYTOPLANKTON GROWTH

Peter G. Brewer and Joel C. Goldman

Continuous cultures of three marine phytoplankton species, *Phaeodactylum tricorutum*, *Dunaliella tertiolecta* and *Monochrysis lutheri*, were monitored for changes in alkalinity of the culture medium resulting from  $\text{NO}_3^-$  and  $\text{NH}_4^+$  uptake. Uptake of  $\text{NO}_3^-$  caused an increase in alkalinity, whereas uptake of  $\text{NH}_4^+$  produced a decrease. These results are consistent with the type of schematic equation proposed by Redfield, Ketchum and Richards (1963) for photosynthetic assimilation of inorganic nitrogen, in which  $\text{NO}_3^-$  uptake is balanced by  $\text{OH}^-$  production and  $\text{NH}_4^+$  uptake leads to  $\text{H}^+$  generation. These reactions suggest uptake of charged nitrogen species by microbes. However, we have been unable to demonstrate the exact stoichiometry of this relationship. The role of P uptake in the alkalinity change is unclear. The data in fact show an offset, functionally equivalent to the production of some strong acid, possibly due to reactions on the walls of the vessel or resulting from active uptake of cations and/or extrusion of  $\text{H}^+$  ions by the growing cells.

Supported by: National Science Foundation Grants GA 22292 and GX 33295 and Energy Research & Development Administration (ERDA) AT(11-1)2532.

## PHYTOPLANKTON RESPONSE TO WASTEWATER NUTRIENT ADDITION IN CONTINUOUS CULTURE

Joel C. Goldman

Three marine phytoplankton, *Dunaliella tertiolecta*, *Phaeodactylum tricorutum*, and *Thalassiosira pseudonana* (3H) were grown on wastewater-seawater mixtures in continuous-flow monocultures. *P. tricorutum* increased in biomass with increasing wastewater additions until a mixture of about 40% wastewater-60% seawater was reached. The other species did not increase in biomass beyond a 20% wastewater-80% seawater mixture and actually displayed some inhibition at higher wastewater additions. The carbon/nitrogen (C/N) ratio of the algae was consistently below 6 when nitrogen was not limiting growth, but increased with decreasing dilution rate under nitrogen-limiting conditions, depending on whether  $\text{NH}_4^+$ -N or  $\text{NO}_3^-$ -N was the main nitrogen source.

Species dominance in enriched cultures is controlled by a complex interaction of environmental factors. By altering the chemical composition (C/N ratio) of dominant phytoplankton such as *P. tricorutum* in mass culture through control of nitrogen source and concentration, it may be possible to increase the nutritional value of these organisms so that they represent a balanced diet for herbivorous shellfish growth.

Supported by: National Science Foundation (RANN) Grant GI 32140.

IDENTIFICATION OF NITROGEN AS A GROWTH-LIMITING NUTRIENT IN WASTEWATERS  
AND COASTAL MARINE WATERS THROUGH CONTINUOUS CULTURE ALGAL ASSAYS

Joel C. Goldman. Collaborators: Mirelle S. Vanpee, Regina N. Carson,  
J. Philip Clarner, Nathaniel Corwin

Two series of continuous culture algal assays conducted in 1973 and 1974, totalling 63 experiments, were performed on mixtures of seawater and wastewater - both treated and untreated - from five locations along the coasts of Massachusetts and Rhode Island. The results conclusively show that nitrogen was the growth-limiting nutrient in these wastewaters and in coastal marine environments receiving such wastes. There was a linear relationship between total inorganic nitrogen ( $\Sigma N$ ) in the influent and particulate nitrogen (PN) representing algal biomass up to a  $\Sigma N$  concentration of about  $10 \text{ mg l}^{-1}$ . In addition the N:P ratios in the test alga, *Phaeodactylum tricoratum*, varied between 10 and 20 (by atoms), whereas the N:P ratios in the wastewater-seawater mixtures were between 4 and 12, thus providing additional evidence that nitrogen was limiting. Enrichment with nitrogen and/or phosphorus to span a range of N:P ratios from 3.9 to 20 resulted in a linear response in PN concentration to  $\Sigma N$  additions. Additions of P had no effect on algal growth. Removal of detergent-P in communities practicing marine waste disposal will hence have little impact on the control of eutrophication in coastal waters.

Supported by: *National Science Foundation Grants GI 32140 and GI 43884; and National Oceanic and Atmospheric Administration Sea Grants 04-4-158-5 and 04-5-158-8.*

NUTRIENT TRANSFORMATIONS IN MASS CULTURES OF MARINE ALGAE

Joel C. Goldman and John H. Ryther. Collaborators: Asa S. Wing,  
Nathaniel Corwin, J. Philip Clarner, Judith A. White, John A. Davidson

Two mass cultures of marine algae were maintained for 24 continuous weeks on mixtures of secondarily treated wastewater and seawater. Nitrogen removal and algal growth were related to both nitrogen loading in the form of variations in the waste-seawater mixture and changes in the dilution rate. Nitrogen assimilation was limited to about  $4 \text{ mg/l}$ . High nitrogen removals were associated with a combination of algal assimilation and ammonia evolution at the high pond pH values attained. Algal concentrations represented as both particulate carbon (PC) and particulate nitrogen (PN) decreased linearly with increases in the dilution rate. Maximum algal yields of  $6 \text{ g PC m}^{-2} \text{ day}^{-1}$  occurred at a dilution rate of  $0.75 \text{ day}^{-1}$ .

Published in: *J. Environ. Engr. Div., American Society of Civil Engineers, 1975.*

Supported by: *National Science Foundation Grant GI 32140 and National Oceanic and Atmospheric Administration Sea Grant 04-4-158-5.*

MASS PRODUCTION OF MARINE ALGAE IN OUTDOOR CULTURES

Joel C. Goldman, John H. Ryther, and LaVergne D. Williams

Algae were cultured in 2000 l ponds, provided with 50% seawater and 50% secondarily treated domestic wastewaters at Woods Hole, Massachusetts and Ft. Pierce, Florida. Results indicate yields were constant between dilution rates of 0.50 and 1.00 (fraction of vol turnover/day) (average of  $12.7 \text{ g dry wt m}^{-2} \text{ d}^{-1}$  at Woods Hole and  $19 \text{ g dry wt m}^{-2} \text{ d}^{-1}$  at Ft. Pierce). They were, however, significantly reduced at a dilution rate of 0.25 and were zero at 1.50 (full washout). In all cases a monoculture developed from the algae present in the natural waters. Seasonal changes are described. This outdoor culture was maintained without difficulty for the six month experimental period. The geographical location had a considerable effect on algal yields, those at Ft. Pierce being  $\sim 50\%$  greater than those at Woods Hole. Production values are comparable with those of fast-growing crops.

Published in: *Nature*, 1975.

Supported by: *National Science Foundation Grant GI-32140 and The Atlantic Foundation.*

RELATIVE GROWTH OF DIFFERENT SPECIES OF MARINE ALGAE  
IN WASTEWATER-SEAWATER MIXTURES

Joel C. Goldman and Helen I. Stanley. Collaborators: John H. Ryther, Edward J. Carpenter, Nathaniel Corwin, John P. Clarnier, James E. Broda, Judith White and Christopher Hopf.

In recent studies we have developed a combined nutrient removal-marine aquaculture process for the tertiary treatment of wastewater and the production of commercially important shellfish. Part of this process consists of an outdoor mass cultivation system for marine algae. During our previous experiments we have observed that marine diatoms almost exclusively are the dominant algal species in our outdoor cultures. To better understand this phenomenon of diatom dominance we grew 16 species of marine algae in continuous monoculture under laboratory conditions that simulated to some degree the conditions that prevailed in our outdoor experiments. Interestingly, species such as *Skeletonema costatum*, *Monochrysis lutheri* and *Tetraselmis* sp., which never have been dominant in our outdoor cultures, grew as well in monoculture as *Phaeodactylum tricornerutum*, a diatom that frequently has been the prevalent species outdoors. However, it was shown that when monocultures of *Dunaliella tertiolecta* and *Thalassiosira pseudonana* (3H) were purposely contaminated with *P. tricornerutum*, the latter species quickly became dominant. It was suggested that a complex interaction of environmental factors is usually responsible for the dominance of a particular species. One such factor may be the nitrogen source in the growth media. Under conditions of virtually complete nitrogen assimilation the carbon to nitrogen ratio in the algae was high (7-8) when  $\text{NO}_3^-$ -N was the source of nitrogen, and low (4-6) when  $\text{NH}_4^+$ -N was the prime form of nitrogen. When algal growth was low so that there was a large residual of inorganic nitrogen, the carbon/nitrogen ratio was low regardless of whether  $\text{NO}_3^-$ -N or  $\text{NH}_4^+$ -N was the main nitrogen source.

The control of algal species in large cultivation systems may be possible through manipulation of operating parameters such as temperature, depth, dilution

rate, mixing nutrient source, etc., once enough information becomes available on the optimum growth conditions for a multitude of species. To date, though, such information is lacking.

Published in: *Marine Biology*. 1975.

Supported by: *National Science Foundation (RANN) Grant GI 43884*.

#### THE ECOLOGY OF MARINE PLANKTONIC DIATOMS

Robert R. L. Guillard and Peter Kilham. Collaborator: Vicki L. McAlister

This review considers the technical problems of sampling, collection and recognition, identification and taxonomy and non-random distribution of diatoms on the small spatial scale. The concept of a diatom species is considered in the light of taxonomic criteria and the existence of ecological races. Concepts used in the study of distribution patterns are reviewed.

The biogeography of marine plankton diatoms is surveyed from a detailed review of the literature. Both distribution of living diatoms in the plankton and distribution of diatom remains (shells) in ocean bottom deposits are considered. Bipolar distributions and endemism are reviewed.

The three stages of succession (usually seasonal) in diatom populations are reviewed. The ecology of diatoms characteristic of oligotrophic (nutrient-poor) water is discussed. The influences of proximate (mechanistic) vs. evolutionary factors in ecological succession are compared and applied to consideration of the evolutionary ecology of planktonic diatoms.

Size-selective predation of diatoms and the chemical differences between oceanic and neritic water are felt to be important factors needing critical study.

Supported by: *National Science Foundation Grant GA 33288 A01*.

#### COEXISTENCE, EQUILIBRIUM, AND NUTRIENT SHARING AMONG PLYTOPLANKTON SPECIES OF THE GULF OF MAINE

Edward M. Hulburt

'If phytoplankton species coexist in equilibrium, then they are prevented from competing so severely for nutrients that one or more of their numbers is excluded.' Hutchinson (1965, p. 113) pointed out, in effect, that the antecedent clause of this conditional must be false. Species coexist but not in equilibrium, because equilibrium is only attained after the better competitors have excluded the poorer competitors. Richerson *et al.*, (1970) presented observations of patchy distribution of species indicating lack of equilibrium in time; in this way they followed Hutchinson's surmise that species can only occur together when equilibrium between them and their nutrient resource and between each other does not prevail. But Peterson (1975) presented a mathematical model in which different species are restricted by different nutrients and thus can coexist in true competitive equilibrium.

Supported by: *Atomic Energy Commission Contract AT(30-1) 1918*.

## LIMITATION OF PHYTOPLANKTON SPECIES IN THE OCEAN OFF WESTERN AFRICA

Edward M. Hulburt

The growth rate of phytoplankton off the west coast of Africa appeared not to be nutrient-limited for two reasons. First, most of the species characteristic of non-upwelling regions did not show increased abundance in upwelling regions where both nutrient and other species were abundant. Second, the half-saturation value for ammonium uptake of the dominant species, *Coccolithus huxleyi*, was one-tenth of the amount of ammonia in the water in part of the non-upwelling region. In an upwelling region, where diatoms dominated, nutrients exceeded the half saturation values characteristic of diatoms.

Supported by: Atomic Energy Commission Contracts AT(30-1)-3862 and AT(11-1)-3564.

## THE MASS OUTDOOR CULTURE OF MACROSCOPIC MARINE ALGAE

Brian E. Lapointe, LaVergne D. Williams, Joel C. Goldman and John H. Ryther

Two species of macroscopic marine algae (Rhodophyceae) were grown and harvested continuously during 1974 in Fort Pierce, Florida. The seaweeds *Gracilaria* sp. and *Hypnea musciformis* were grown in both 600 l and 50 l tanks in the third stage of a nutrient removal-aquaculture process that included microscopic marine algae and oysters in the first two stages. Mixtures of secondarily treated wastewater and seawater constituted the initial nutrient source, with the seaweeds utilizing nutrients not assimilated by the microscopic algae or regenerated by the oysters. Standing crops of up to 7900 g wet weight of *Hypnea* and 9000 g *Gracilaria* were maintained. The *Hypnea* cultures could not be maintained beyond June when tank temperatures reached 30°C, but *Gracilaria* grew during the entire year. On the basis of periodic harvesting of a portion of the standing crops, yields were consistently between 12 and 17 g dry weight/m<sup>2</sup>/day for both species. These yields are as high as have been achieved for mass cultures of microscopic marine algae and for fast-growing commercial crops such as sugar and rice.

Supported by: Harbor Branch Foundation and National Science Foundation (RANN) Grant GI 43884.

## BIOCHEMICAL TAXONOMY OF MARINE PHYTOPLANKTON BY ELECTROPHORESIS OF ENZYMES. I.

Lynda S. Murphy and Robert R. L. Guillard

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 - i.e., to 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* Hasle and Heimdal and *T. fluviatilis* Hustedt. The four clones of *T. fluviatilis* form a distinct group, clearly separated from all the *T. pseudonana* clones. Within *T. pseudonana*, four estuarine clones and one reef clone form a group that is distinctly different from four oceanic clones. A single

clone of *T. pseudonana* from the Continental Shelf waters is intermediate between these two groups and probably 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 originated from different continents, and that 2) *T. pseudonana* is subdivided into ecological races.

Supported by: *National Science Foundation Grant GB 33288.*

*COLLECTION OF DINOFLAGELLATES AND OTHER MARINE FLAGELLATES  
BY CENTRIFUGATION IN DENSITY GRADIENTS OF SILICA SOL*

Carl A. Price and Robert R. L. Guillard

We describe an improved medium, named "sorbitol sea water" (SSW), for the collection and concentration of marine phytoplankton by centrifugation into density gradients of silica. SSW is a partially synthetic sea water which is at once compatible with colloidal silica (Ludox AM) and supports lowered but otherwise normal motility of two naked dinoflagellates and two other fragile flagellates: *Gymnodinium nelsoni*, *Gymnodinium* sp., *Olisthodiscus luteus*, and *Pavlova* sp. Following isopycnic sedimentation into continuous or step gradients of Ludox AM in SSW, the organisms are concentrated in narrow zones and can be recovered more completely intact than from simple pelleting. Together with previously described methods, the medium should be useful in collecting morphologically and physiologically intact phytoplankton from marine waters.

Supported by: *a grant from the U. S. National Marine Fisheries Service, National Science Foundation Grant GB 33288, and journal paper of the New Jersey Agricultural Experiment Station.*

*PHYSICAL MODELS OF INTEGRATED WASTE RECYCLING-MARINE POLYCULTURE SYSTEMS*

John H. Ryther, Joel C. Goldman, Cameron E. Gifford, John E. Huguenin,  
Asa S. Wing, J. Philip Clarner, Lavergne D. Williams and Brian E. Lapointe

A combined tertiary sewage treatment - marine aquaculture system has been developed, tested and evaluated using several different experimental sizes and configurations located both at Woods Hole, Mass. and Fort Pierce, Fla. Domestic wastewater effluent from secondary sewage treatment, mixed with sea water, is used as a source of nutrients for growing unicellular marine algae and the algae, in turn, are fed to oysters, clams, and other bivalve molluscs.

Solid wastes from the shellfish are fed upon by polychaete worms, amphipods, and other small invertebrates that serve as food for flounder, lobsters, and other commercially valuable secondary crops. Dissolved wastes excreted by the shellfish and other animals and any nutrients not initially removed by the unicellular algae are removed by various species of commercial red seaweeds (*Chondrus*, *Gracilaria*, *Agardhiella*, *Hypnea*) as a final 'polishing' step. The final effluent from the system is virtually free of inorganic nitrogen and is incapable of supporting further growth of marine life or of contributing to eutrophication of the receiving waters.

A description of experiments with the above food chains and preliminary results with some alternative approaches are discussed, including a detailed account of the nitrogen mass balance through all of the components of one of the experimental systems.

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## ZOOPLANKTON

*THE SIPHONOPHORE BathypHYSA sibogae LENS AND VAN RIEMSDIJK, 1908, IN THE SARGASSO SEA, WITH NOTES ON ITS NATURAL HISTORY.*

Douglas C. Biggs and G. Richard Harbison

Eleven specimens of the cystonect siphonophore, *BathypHYSA sibogae* Lens and van Riemsdijk, 1908, were collected by SCUBA divers in the upper 30 m of the Sargasso Sea. The fishing behavior of the living animal is described. The hyperiid amphipod, *Schizoscelus ornatus* Claus, 1879, seems to be preferentially associated with this siphonophore.

Supported by: *National Science Foundation Graduate Fellowship and National Science Foundation Grant GA 39976.*

*COMBINED TOXICITY OF FREE CHLORINE, CHLORAMINE AND TEMPERATURE TO STAGE I LARVAE OF THE AMERICAN LOBSTER Homarus americanus.*

Judith M. Capuzzo, Sarah A. Lawrence and John A. Davidson

The differential effects of free chlorine and chloramine on Stage I larvae of the American lobster *Homarus americanus* have been investigated in continuous flow bioassay units. Applied chloramine was more toxic than corresponding concentrations of applied free chlorine to lobster larvae with estimated LC<sub>50</sub> values at 25°C of 16.30 mg/l applied free chlorine and 2.02 mg/l applied chloramine. The synergistic effect of temperature on the toxicity of both free chlorine and chloramine has also been demonstrated. Exposure to applied free chlorine at 20°C resulted in no significant mortality of test organisms, whereas exposure at 30°C resulted in an estimated LC<sub>50</sub> value of 2.50 mg/l. Applied chloramine was considerably more toxic with an estimated LC<sub>50</sub> value at 20°C of 4.08 mg/l and at 30°C of 0.56 mg/l.

The action of each toxicant appeared to be an alteration of metabolic activity as revealed by changes in respiration rates during and after exposure to applied free chlorine and chloramine. Initial respiratory stress was detected during exposure to 0.05 mg/l applied chloramine and 5.00 mg/l applied free chlorine; reductions in respiration rates 48 hours after exposure were observed with exposure to all concentrations tested with similar results being obtained following exposure to 0.05 mg/l applied chloramine and 0.10 mg/l applied free chlorine. These results indicate the need for information in addition to that obtained in standard bioassays for an adequate assessment of chlorine toxicity.

The apparent chlorine demand of the sea water used in this study was determined after removal of particulate and dissolved organics and ammonia. Approximately 18% of the applied level of free chlorine and chloramine was recovered as residuals, measured by amperometric titration; however, no reason for this low recovery has

been determined. Until it has been established that undetected chlorine and chloramine in sea water does not result in the production of toxic compounds, both applied and residual levels should be reported in toxicity studies.

Supported by: *Energy Research and Development Administration (ERDA)*  
*AT(11-1)-2532.*

*THE DEVELOPMENTAL STAGES OF Pontella meadi WHEELER (COPEPODA: CALANOIDA)*

Victoria R. Gibson and George D. Grice

The complete development of *Pontella meadi* is described and illustrated on the basis of nauplii and copepodids cultured in the laboratory and collected in the field. Development from nauplius to adult takes from 18 - 25 days at 20°C when animals are fed dinoflagellates and *Artemia* nauplii.

Supported by: *National Science Foundation Grant GA 43126.*

*VARIATION IN ZOOPLANKTON ABUNDANCE IN COPPER-CONTAMINATED  
ENCLOSED WATER COLUMNS*

Victoria R. Gibson and George D. Grice. Collaborator: Thomas J. Lawson, Jr.

Fluctuations in zooplankton abundance and species composition are described for two copper experiments conducted in Controlled Experimental Ecosystems during 1974. Copper concentrations of 5, 10 and 50 ppb were tested. The major phenomenon in both experiments was a severe reduction (>80%) in the abundance of zooplankton in all CEEs, control as well as copper polluted. A portion of the population decline was attributed to grazing by carnivorous ctenophores and medusae, making it difficult to quantitatively assess the effects of copper. Estimates of copper-induced zooplankton mortality vary from approximately 5 - 20%.

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*OCCURRENCE, VIABILITY AND SIGNIFICANCE OF RESTING EGGS  
OF THE CALANOID COPEPOD Labidocera aestiva*

George D. Grice and Victoria R. Gibson

Field and laboratory observations on the occurrence and viability of eggs of *Labidocera aestiva* Wheeler show that eggs of this temperate species which are laid in late fall remain viable on the bottom and hatch in late spring. These eggs thereby provide the means of repopulating temperate areas with this species after its winter disappearance from the plankton.

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Supported by: *National Science Foundation Grant GA-43126.*



THE DEVELOPMENT OF *Lycaea pulex* AND *Lycaea vincentii*  
(HYPERIIDAE: LYCAEIDAE)

G. Richard Harbison

The development of *Lycaea pulex* Marion, 1874, is described and contrasted with that of *L. vincentii* Stebbing, 1888. The two species differ in three respects - the shape of the male first antenna, the absence of serrations on pereopod 5 in the former species, and in the proportions of the first uropods. *Lycaea pulex* does not have a specialized larval stage, as does *Brachyscelus cruscolum* Bate, 1861, which was thought to be closely allied. The Lycaeidae seem to occupy an intermediate position between the Oxycephalidae and other families of the Platysceloidea.

Supported by: National Science Foundation Grants GA 39976 and GA 31983.

FEEDING RATES OF *Pegea confederata* AND SOME OTHER SALPS

G. Richard Harbison and Ronald W. Gilmer

The filtration rates of the salps, *Pegea confederata*, *Salpa maxima*, and *Cyclo-salpa affinis* were measured. Filtration rates increase exponentially with increasing length and body carbon. Overall filtration rates of more than 100 ml/min were recorded. The mucous net of *Pegea confederata* can retain particles as small as 0.7 micron. There appears to be no change in filtration rate with changes in particle concentration. Filtration rate/ $\mu$ g carbon increases with increasing size, in contrast to ascidians. It is hypothesized that this may be due to the fact that salps use muscular pumping, rather than ciliary currents, to transport water. The filtration rates we have recorded suggest that the role of salps in the open ecosystem may be more important than has been assumed previously.

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SMALL-SCALE PATTERN OF A CALIFORNIA CURRENT ZOOPLANKTON ASSEMBLAGE

Loren R. Haury

The small-scale vertical (10's of meters) and horizontal (100's to 1000's of meters) distribution of zooplankton in the California Current near Guadalupe Island, Baja California, Mexico, was studied. Vertical distributions were sampled using a vertically towed Longhurst-Hardy Plankton Recorder which gave a sequence of samples, each integrated over about 5 m, from 250 m to the surface. Because of the sampling biases of the LHPR, details in vertical structure of less than 15 to 20 m were not considered. The pattern of the vertical tows and the variability of the integrated counts of species were used to infer horizontal distribution. Four series of eight tows each were taken around noon and midnight over a two-day period. Four of the eight tows in each series were randomly positioned within 2000 m of a parachute drogue (first day) or a fixed geographic position (second day); four were replicate tows taken at the drogue or the fixed position. Sixty-seven taxonomic categories were counted.

The replicate tows, separated by no more than a few hundred meters, gave more similar vertical profiles for species than did the random tows, with separations of

100's to 1000's of meters. The night replicate tows showed less variability in depth distribution than did either the night random or any of the day tows, leading to the hypothesis that the vertical distributions observed were generated by interactions of the organisms' diel behavior with internal waves. Variability of abundance estimates using the integrated counts was the same for both replicate and random tows, indicating horizontal patches may be smaller than 100 m. No evidence was found for a day-night change in patch size, or for a consistent overlapping of patches of different species.

Replicate tows gave more similar estimates of community structure (relative proportions of species) than random tows. Overall day community structure was more similar between tows than night structure. Similarity in species proportions of any random tow to the replicate tows or to other random tows of a series decreased with increasing distance between the tows being compared. This decrease was greater for the night samples, suggesting community structure is more heterogeneous at night.

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A COMPARISON OF ZOOPLANKTON PATTERNS IN THE CALIFORNIA CURRENT  
AND NORTH PACIFIC CENTRAL GYRE

Loren R. Haury

This study compares the small-scale (100's to 1000's of meters) horizontal spatial distribution of zooplankton from stations in the California Current (29°N, 118°W) and in the North Pacific Central Gyre (31°N, 155°W). Patterns were inferred from the spacing of vertical tows and the variability in abundance of 15 taxonomic categories caught in these tows. In the California Current, four tows were taken at random positions within 2000 m of a drogue or fixed geographic position and four replicate tows were taken at the drogue or the fixed point. Four series of these eight tows were taken around noon and midnight during two days. At the Central Gyre station, two similar series (one day and one night) were taken while following a drogue.

Estimates of the scale of structure based on comparisons of replicate and random tow variability suggest that aggregated patterns in the Central Gyre are larger than a few hundred meters, while the California Current structures may be less than 100 m in size. Day-night changes in patch size were not apparent in either area. Evidence for multispecies patches was found only for the Central Gyre station.

Replicate samples in both areas gave more consistent measures of community structure (relative proportions of species) than the random tows. Similarity of community structure decreased with increasing distance between tows being compared. The decrease was much greater for the California Current station, a further indication of smaller patch size in this area. Diurnal changes in community structure occurred in both areas.

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*LONGHURST-HARDY PLANKTON RECORDERS: THEIR DESIGN AND USE TO MINIMIZE BIAS*

Loren R. Haury, Peter H. Wiebe, Steven H. Boyd. Collaborator: Alfred Morton

Field studies, using SCUBA divers, and tow basin experiments of Longhurst-Hardy Plankton Recorder biases were conducted by injecting various types of particles into a Longhurst-Hardy Plankton Recorder (LHPR) having a variety of net and recorder box configurations. Tow speed and clogging were also considered. The following factors contributed to biases: 1) low recorder gauze aperture area to throat area ratios, causing backing up of flow into the net cod end, especially as the gauze clogs; 2) tunnel gauze slot design, allowing significant losses of particles; 3) steep side angles of the net at the recorder entrance due to bagging caused by improperly tensioned nets and to radial stretching of fine mesh nets at higher tow speeds; 4) clogging of the net ahead of the LHPR; 5) short nets (less than about four mouth diameters in length); 6) fast tow speeds (greater than about  $125 \text{ cm sec}^{-1}$ ). Experiments with an LHPR modified to minimize biases showed that resolution to 15 m in oligotrophic waters is feasible. In eutrophic waters, we doubt it is feasible to use a net with the LHPR. LHPR sampling performance should be monitored continuously to detect biases in the field.

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*ZOOPLANKTON SAMPLING VARIABILITY IN PLASTIC ENCLOSURES*

Thomas J. Lawson and George D. Grice

Zooplankton sampling variability in Controlled Experimental Ecosystems (CEEs) was investigated using a small, vertically-hauled net and a Schindler plankton trap. Following sampling, all the zooplankton in the CEEs were collected by filtering the water as it was pumped out. Based on precision, accuracy and comparability between experiments, vertically integrated net hauls provide the best measure of zooplankton abundance in CEEs.

Supported by: *National Science Foundation Grant GX 42580.*

*CRUSTACEAN PLANKTON COMMUNITIES OF THE MATAMEK RIVER SYSTEM  
AND THEIR VARIATION WITH PREDATION*

Gregory F. Pope and John C. H. Carter

The crustacean plankton communities of several lakes which varied in their species and densities of fish planktivores and *Chaoborus* larvae were examined. The plankton communities of lakes with fish planktivores and low densities of *Chaoborus* larvae contained greater numbers of non-cyclopoid crustacean predators but lower numbers of the larger herbivores. Lakes with brook trout only and low densities of *Chaoborus* larvae, had plankton communities whose biomasses were dominated by the larger herbivores. The communities of lakes with no fish and high densities of larvae were dominated by the smaller herbivores although the larger species were present in some. The non-cyclopoid crustacean predators were absent from almost all of these lakes.

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Supported by: *The Atlantic Foundation.*

*A METHOD FOR RESTRAINING LIVING PLANKTONIC CRUSTACEANS*

Loren R. Haury

Small living crustaceans can be mounted on the tip of nylon monofilament line by using "instant" drying polymer glue. This method allows continuous microscopic observation of feeding and swimming mechanisms in relatively large volumes of water.

Supported by: *National Science Foundation Grant GA 41188.*

*ENERGETICALLY EFFICIENT SWIMMING BEHAVIOR OF NEGATIVELY BUOYANT ZOOPLANKTON*

Loren R. Haury, Daniel Weihs

A number of species of negatively buoyant zooplankton perform a swimming behavior characterized by a repeated upwards swimming followed by passive sinking. This hop and sink behavior is shown theoretically to save energy relative to continuous swimming at a fixed depth. The maximum energy savings is a function of the drag ratio and speeds of swimming and sinking.

Supported by: *National Science Foundation Grant GA 41188.*

*CONTROLLED ENVIRONMENTAL POLLUTION EXPERIMENT (CEPEX) AND ITS USEFULNESS  
IN THE STUDY OF LARGER MARINE ZOOPLANKTON UNDER TOXIC STRESS*

Michael R. Reeve, George D. Grice, Victoria R. Gibson,  
Mary Ann Walter, Karen Darcy and Tsutomu Ikeda

Experiments on marine zooplankton showed that acute toxicity of copper and mercury is a function of biomass, that species may be either relatively less or more tolerant than the average, and that different populations of the same species could show wide variability. It was demonstrated that sublethal effects on fecal pellet and egg production in copepods could result from short-term exposure to 5 ppb copper. Population changes of the larger zooplankton in enclosed water columns with concentrations of 0, 10 and 50 ppb copper are discussed.

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*A MULTIPLE OPENING/CLOSING NET AND ENVIRONMENTAL SENSING SYSTEM  
FOR SAMPLING MARINE ZOOPLANKTON*

Peter H. Wiebe, Kenneth H. Burt, Steven H. Boyd, and Alfred W. Morton

The Multiple Opening/Closing Net Environmental Sensing System (MOCNESS) is based on the Tucker Trawl principal and has nine rectangular nets (1 m x 1.4 m) which are opened and closed sequentially by commands through conducting cable from the surface. Environmental sensors to measure conductivity, temperature, and depth are attached to the net support frame. In addition, sensors to monitor flow past the net and the angle of the net assembly from the vertical, and indicators to record the electrical and mechanical function of the opening/closing mechanism are present. All data are transmitted to the surface via the cable for recording on magnetic tape and digital display. The data may also be fed into a computer

for real time processing and plotting. A field performance study has demonstrated that MOCNESS can provide either eight stratified oblique samples or eight serial horizontal samples per tow at a substantial savings in time over other opening/closing systems while also obtaining environmental data.

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*GULF STREAM COLD CORE RINGS: LARGE SCALE INTERACTION SITES  
FOR OPEN OCEAN PLANKTONIC COMMUNITIES*

Peter H. Wiebe, Edward M. Hulburt, Edward J. Carpenter, Andrew E. Jahn,  
George P. Knapp, III, Steven H. Boyd, Peter B. Ortner, James L. Cox

Gulf Stream cold core rings are major oceanographic features occurring in the Northwestern Atlantic Ocean. In the process of formation, cold water of slope origin and the associated flora and fauna are entrapped within a ring of Gulf Stream water. These systems generally move southwesterly into the Sargasso Sea. Rings are of biological interest because they offer a unique approach to the problem of assessing the relative importance of physical and biotic factors as determinants of the distribution and abundance of planktonic organisms. In effect, the formation and consequent evolution of a cold core ring represents a large scale ecological field experiment wherein major environmental changes are gradually imposed on a plankton community.

Four cruises have been made to sample Gulf Stream Rings and the surrounding Sargasso Sea. Biomass and counts of selected species of zooplankton, phytoplankton, and midwater fish populations have been assessed. Concomitant hydrocasts have yielded physico-chemical data.

Although a ring may remain physically identifiable for as long as two years, decay of the initially distinct biological community appears to be more rapid. A characteristic zooplankton assemblage appears to persist longer than the initial phytoplankton assemblage. The season of formation appears to be of critical importance in determining the biological evolution of a Gulf Stream ring. The rapid decay rate of the Slope Water species assemblage in rings may occur as a result of biological interactions with the Sargasso Sea assemblage initiated by the rapid modification of physical and chemical properties of ring surface waters.

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## BENTHOS

SIBLING SPECIES IN THE MARINE POLLUTION INDICATOR *Capitella (Polychaeta)*

Judith P. Grassle and J. Frederick Grassle

Electrophoretic patterns for eight enzyme loci clearly distinguish six sibling species in the well-known pollution indicator worm, *Capitella capitata*. Unlike sibling species of *Drosophila* the *Capitella* species have virtually no alleles in common. Close examination has revealed only slight morphological differences between species, while life histories and reproductive modes are very distinct. The *Capitella* species are ideally suited for genetic and evolutionary studies.

Supported by: *National Science Foundation Grant GA 35393.*

TEMPORAL ADAPTATIONS IN SIBLING SPECIES OF *Capitella*

J. Frederick Grassle and Judith P. Grassle. Collaborators: Rudolph S. Sheltema, Richard J. Hoffmann, Judith Ashmore and Ann White

Previously thought to be a single species, *Capitella capitata* is a complex of at least six sibling species. These species show virtually no genetic similarity at 10 loci studied electrophoretically. Close examination of the species in culture revealed life history differences and slight morphological differences between the types. As a result of life history differences the species partition the environment temporally, with each life history adapted to a somewhat different pattern of environmental uncertainty. The classification and evolution of temporal adaptations are discussed.

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## PATTERN AND ZONATION: A STUDY OF THE BATHYAL MEGAFUNA USING THE RESEARCH SUBMERSIBLE Alvin

J. Frederick Grassle, Howard L. Sanders, Robert R. Hessler, Gilbert T. Rowe, Tracy K. McLellan. Collaborators: Rudolf S. Scheltema, George Hampson, Eric Barham, Woollcott K. Smith, Linda M. Cole, Susan P. Garner, Judith P. Grassle and ALVIN group.

The pattern of distribution of benthic megafauna (defined as the animals readily visible in photographs) on the Gay Head-Bermuda transect differs considerably at the three scales measured: within photographs, between photographs and between depths. Detailed natural history observations are given for a series of dives at 1300 and 1800 m. The composition of the megafauna varies markedly between the five depths studied (500, 1000, 1300, 1500 and 1800 m). This corresponds with the high rate of depth-correlated species replacement described elsewhere for the macrofauna. Relative to the macrofauna, the megafauna provides virtually no information on density and diversity in the deep sea. Within a single depth the dominant pattern of species distribution is random, both between and within individual photographs. A regular or even pattern occurs in the brittle star, *Ophiomusium*

*Lymani*, owing to spacing of individuals at high densities. The most pronounced aggregation occurs in the sea urchin, *Phormosoma placenta*. This deposit-feeding species continually moves as it depletes its food resources in one spot. Unlike *Phormosoma*, the other sea urchin, *Echinus affinis* sometimes responds to concentrations of food although only relatively weak aggregations appear in the photographs analyzed. Thus, the food of this species is not usually concentrated. The patchiness of *Ophiomusium* at low densities is attributed to avoidance of disturbed areas that appear as large burrow-like depressions.

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A SIMILARITY MEASURE SENSITIVE TO THE CONTRIBUTION OF RARE SPECIES  
AND ITS USE IN INVESTIGATION OF VARIATION IN BENTHIC COMMUNITIES

J. Frederick Grassle and Woollcott K. Smith

We propose a new measure of similarity, the normalized expected species shared or NESS. The measure is based on the expected number of species shared between random samples of size,  $m$ , drawn from a population. The NESS measure is shown to be a generalization of Morisita's similarity and is demonstrated to be less biased than other commonly-used measures. The contribution of dominant and rare species is explicit according to the sample size,  $m$ , chosen. For large  $m$ , NESS is sensitive to the less common species in the populations to be compared. To illustrate the usefulness of the NESS measure two quite different marine benthic examples are presented. In each case the presence or absence of the less common species is an important consideration. The spatial and temporal relationships of the benthic samples can be predicted from the cluster diagrams based on the NESS similarities.

Supported by: *National Science Foundation Grant GB 36554.*

GENETIC VARIABILITY IN DEEP-SEA ECHINODERMS

Lynda S. Murphy, Gilbert T. Rowe and Richard L. Haedrich

The electrophoretic mobility of enzymes in polyacrylamide gels was used as a measure of genetic variability in deep-sea echinoderms. Both variable and monomorphic species were found. The levels of polymorphism and heterozygosity were similar to those of species living in shallow-water and terrestrial environments, evidence that these are unrelated to climatic stability. We propose that polymorphism is more probably related to the intensity of selection pressures and a reflection of biological fluctuations.

A tendency toward a deficiency of heterozygotes from the number expected in Hardy-Weinberg equilibrium suggests that populations of the ophiuroid *Ophiomusium Lymani* may be genetically isolated.

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*THE ESCAPE OF VELIGERS FROM THE EGG CAPSULES OF Nassarius obsoletus  
AND Nassarius trivittatus (Gastropods, Prosobranchia)*

Jan A. Pechinik. Collaborators: Frank G. Carey, Charles E. Holt, III,  
Rudolf S. Scheltema, John M. Teal, Ruth D. Turner

1. The loosening of the egg capsule plug prior to escape of the veligers is shown to be chemically mediated in *Nassarius obsoletus* and *N. trivittatus*.
2. The hatching substance is not produced continuously during development, but rather in a short pulse beginning just prior to hatching and ending within four hours of escaping from the capsule, for *N. obsoletus*.
3. The hatching substance produced by the embryos of one species is effective only on the capsule plugs of that species, for the two species studied.
4. The substance is functionally short-lived, at room temperature in sea water, losing its potency within three hours after its secretion by *N. obsoletus*.

Published in: *Biological Bulletin*

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*NUTRIENT REGENERATION IN SEDIMENTS OFF CAP BLANC, SPANISH SAHARA*

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

Fluxes of nutrients out of the bottom sediments were measured off Cap Blanc, Spanish Sahara, by *in situ* incubation of the bottom under bell jars. The relationship of Si/N/P regenerated averaged 11/8/1. The average total nitrogen flux out of the sediments ( $410.7 \mu\text{g-atm N m}^{-2}\text{hr}^{-1}$ ) would account for approximately 30-40% of the nitrogen presumed to be required for photosynthesis. Pore water nutrient concentrations were high over the 60 n.mi. square area investigated during the JOINT I expedition, but tended to decrease offshore in deep water, and it can be presumed that sediment to bottom water fluxes of nutrients followed a similar trend.

Supported by: *National Science Foundation Grant GA 33502.*

*BENTHIC-PELAGIC COUPLING IN THE MID-ATLANTIC BIGHT*

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

The hypothesis that the continental shelf is an important site of nutrient regeneration is supported by relatively close agreement between hydrographic data collected in Mid-Atlantic Bight and a theoretical relationship between bottom oxygen demand and the breakdown of sediment organic matter. Nutrient flux out of the bottom is estimated from near-bottom ammonia gradients in a finite difference equation.

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*BENTHIC - PELAGIC COUPLING IN THE NEW YORK BIGHT*

Gilbert T. Rowe, Kenneth L. Smith, Jr., C. Hovey Clifford

Benthic-pelagic coupling is the interdependence between the biota of the water column and the biota on the bottom. For example, organic matter synthesized by phytoplankton supplies energy to the benthos, whereas the phytoplankton depend on heterotrophic benthic metabolism to regenerate the dissolved inorganic nutrients necessary for photosynthesis. Bottom sediment oxygen consumption can be used to estimate how much of the energy incorporated by the phytoplankton is utilized by the benthos, and such rates are directly related to temperature, organic matter in the sediment, availability of dissolved oxygen, and primary production in the water column. Nutrient flux out of sediments has been measured directly by incubating areas of bottom under bell jar-like chambers. Fluxes of major inorganic plant nutrients are often high, indicating that in most nearshore environments most regeneration occurs on the bottom.

Studies in New York Bight were initiated because of the intensity of the fertilization processes there. Oxygen consumption by the bottom was measured in four different seasons, and we concluded it was high enough to oxidize a large fraction of the daily input of sludge. Bottom water ammonia gradients suggested too that remineralization rates were high on the bottom in New York Bight. Samples taken in August 1975 in Christiaensen Basin, along with measurements *in situ* of ammonia flux from the bottom, confirmed that the sediments enriched by sewage sludge are regenerating nutrients but at that time at rates somewhat below our earlier predicted rates for the mid-Atlantic Bight.

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*STUDIES ON THE DEEP SEA PROTOBRANCHIA (BIVALVIA):  
THE FAMILY TINDARIIDAE AND THE GENUS Pseudotindaria.*

Howard L. Sanders and John A. Allen. Collaborators: Linda M. Cole,  
George R. Hampson, Susan P. Garner

A new family of bivalves, the Tindariidae, is erected to include those members of the subclass Protobranchia that have a rounded, concentrically-lined robust shell, a strong hinge plate continuous below the umbo supporting a series of well-developed chevron-shaped teeth, an external ligament, without siphons but having fringing papillae around the incurrent region, palp with few ridges and gill with few plates. A new non-tindariid genus, *Pseudotindaria*, is described to include those protobranchs that have shell morphologies that are very similar to the Tindariidae but with soft parts that are markedly different. The pseudotindariids are siphonate and lack papillae, the palp has many ridges and the gill is composed of many plates. Two new species are described, *Tindaria hessleria* and *T. miniscula*. The hard- and soft-part anatomy, morphological variation, gametogenesis, zoogeography and vertical distribution of four tindariid and two pseudotindariid species are discussed. On the basis of shell morphology, there is no reason why the tindariid and pseudotindariid protobranchs should not be the modern descendants of the paleozoic ctenodonts, the oldest lineage of protobranchs with typical chevron-shaped teeth.

Supported by: *National Science Foundation Grant GB 36554.*

TWO NEW APLACOPHORAN SPECIES FROM OFF WEST AFRICA, *Chaetoderma abidjanense*  
AND *C. majusculum*, CHARACTERIZED BY MENSURATION AND SCANNING ELECTRON MICROSCOPY

Amelie H. Scheltema. Collatorators: Virginia B. Peters,  
Arthur Humes, Rudolf S. Scheltema

The new aplacophoron species from off the Ivory Coast, *Chaetoderma adidjanense* and *Chaetoderma majusculum*, are described by body dimensions and ratios, radula dimensions and ratios, and spicules drawn from light microscope images interpreted by scanning electron microscopy.

DISPERSAL OF MARINE INVERTEBRATE ORGANISMS:  
PALEOBIOGEOGRAPHIC AND BIOSTRATIGRAPHIC IMPLICATIONS

Rudolf S. Scheltema. Collatorator: Isabelle P. Williams

Compelling evidence that pelagic larvae are a means whereby benthic and sedentary marine invertebrate organisms are commonly dispersed along coastlines and across zoogeographic barriers comes from knowledge that larval stages occur regularly within all temperate and tropical nearshore waters - over continental shelves, in shallow enclosed seas, and also within major ocean currents that cross ocean basins.

Supported by: *National Science Foundation Grant GA 40144.*

THE SIGNIFICANCE OF PELAGIC LARVAL DEVELOPMENT TO MARINE FOULING ORGANISMS

Rudolf S. Scheltema. Collaborator: Isabelle P. Williams.

Almost all marine fouling organisms have some form of free-living larval stage. The length of the pelagic stage differs widely among various invertebrate species from a few hours, as occurs among serpulid worms, to several weeks, characteristic for barnacles, or even six months to a year for some tropical gastropod species. The principal biological significance of this pelagic larval development to marine fouling organisms can be conveniently summarized in three points. First, planktonic larvae maintain the distribution of a species and also present the constant possibility of enlarging the geographical range when additional habitat becomes available. Second, by their dispersal larvae they implement genetic exchange (or so-called gene flow) between populations thereby influencing the amount of genetically determined geographic variation found within species. Third, larvae serve in habitat selection, that is, they determine through the act of settlement the place where the adult sessile forms will become permanently attached; consequently, larvae may influence the intra- and inter-specific associations within fouling communities.

Marine fouling studies in the past have been largely empirical dealing principally with the efficacy of particular treatments for its prevention. However, adequate solutions to some of the problems of marine fouling require more precise biological information on individual species (e.g., Morphology and physiology of sense receptors at the time of attachment; settlement responses and behavior at settlement; and genetically determined geographic variation in growth and settlement preferences). Only with such improved knowledge is it likely that new approaches to the control of marine fouling will present themselves.

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MORPHOLOGIC VARIABILITY DUE TO ENVIRONMENTAL VERSUS GENETIC CAUSES  
IN COLONIES OF THE PHYLUM ECTOPROCTA FROM THE DEEP SEA

Thomas J. M. Schopf

Ectoprocts are colonial animals and this permits the partitioning of their morphologic variability into components of within-colony (i.e. within a single genotype) and between-colony (i.e. between genotype) variance. These data have been obtained for four species of the deep-sea endemic genus *Euginoma* for a series of characters. Population (between-colony) variance contributed significantly to the total variance in 21% of the comparisons (5 of 24); colony (within group) variance contributed significantly to the total variance in 50% of the comparisons (12 of 24); and both population and colony variance contributed prominently to 29% of the comparisons (7 of 24). Thus in 79% of the comparisons an estimate of the total variance based on that portion of the total variance within colonies is not significantly altered by an added estimate of the variance between colonies. Data of a comparable nature do not seem available for shallow-water species. However from guide lines developed in this study based on coefficients of variability, deep-sea forms appear to have a significantly lower total variance than shallow-water species. The interpretation favored here is that variability attributable to between-colony genotypic differences is very low in the temporally and spatially homogeneous deep-sea environment, and that micro-environmental factors contribute to high within colony variability. In contrast, species of the more variable shallow-water region are anticipated to have a larger proportion of the total variance associated with the between-colony component of the total variance.

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A DIVERSITY INDEX AND ITS SAMPLING PROPERTIES

Woollcott K. Smith and J. Frederick Grassle. Collaborator: Linda M. Cole

A generalization of Simpson's diversity index is defined as the expected number of species in a random sample of size  $m$ . This diversity measure is shown to have a minimum variance unbiased estimator, and the variance of this estimator can be obtained. Several examples are given, and the expected species index is compared with Shannon's information measure. Because of its well-defined statistical properties the expected species measure can be used to present clearly spatial and temporal variability in the diversity of natural communities.

Supported by: *National Science Foundation Grant DES 72-01698.*

SLOW GROWTH RATE OF A DEEP-SEA CLAM DETERMINED BY  $^{228}\text{Ra}$  CHRONOLOGY

Karl K. Turekian, J. Kirk Cochran, D. P. Kharkar, Robert M. Cerrato,  
J. Rimas Vaisnys, Howard L. Sanders, J. Frederick Grassle, John A. Allen  
Collaborators: Susan P. Garner, Linda M. Cole, Donald Rhoads

The age of a deep-sea clam, *Tindaria callistiformis*, from 3800 m depth has been determined by  $^{228}\text{Ra}$  (6.7 year half-life) chronology of separated size fractions of a captured population. A length of 8.4 mm is attained in about 100 years. Shells of this size fraction show about 100 regularly-spaced bands, indicating that the growth feature may be an annual one.

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*PARTICULATE MATTER SINKING TO THE DEEP-SEA FLOOR AT 2000 m IN THE TONGUE OF THE OCEAN, BAHAMAS WITH A DESCRIPTION OF A NEW SEDIMENTATION TRAP*

Peter H. Wiebe, Steven H. Boyd, and Clifford Winget

A sedimentation trap for use just above the deep-sea floor was free-fallen to a depth of 2150 m in the Tongue of the Ocean canyon on January 3, 1974. On March 6, it was successfully recovered with the assistance of DSRV *ALVIN*. The trap has a base one meter square and a height of 30 cm. At the trap bottom are filters to retain falling particles. Two spring-powered sliding doors, each 1 m x 0.5 m, are used to close off the lower 2 cm of the trap during ascent to prevent disturbance of the particles collected on the filters.

Total carbon on the filters as determined by high temperature combustion averaged 1568 mgC/m<sup>2</sup> or an average on a daily basis of 24.9 mgC/m<sup>2</sup>. Similar filter aliquots were fumed over cold phosphoric acid for one hour to eliminate the inorganic fraction. The resulting carbon values ( $\bar{X}$ =6/35 mgC/m<sup>2</sup>/day) suggest 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. Counts of fecal pellets resulted in an estimate of an average of ~ 650 pellets/m<sup>2</sup>/day. Average pellet length was 241 μm and diameter was 109 μm. In laboratory experiments the pellets sank at rates varying between 50 m/day to 941 m/day ( $\bar{X}$  at 5°C = 159 m/day).

Comparison of the sedimentation trap estimates of organic carbon input to the sea floor in this area with benthic energy requirements indicates that rapidly sinking small particulate matter could supply from 10 to 25% of the benthic requirements.

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## FISHES

*PELAGIC FAUNAL PROVINCES AND SOUND-SCATTERING LEVELS IN THE NORTH ATLANTIC OCEAN*

Richard H. Backus and James E. Craddock

An earlier, incomplete scheme of dividing the North Atlantic Ocean into pelagic faunal provinces (Backus *et al.* 1970) has been shown to have value as a scheme of sound-scattering provinces (Chapman *et al.* 1974). The present paper extends and refines the earlier scheme of faunal provinces and, based upon the size of mid-water fish catches, shows how volume reverberation levels can be expected to change from province to province.

Supported by: *National Science Foundation Grant DES 74-23209.*

*DIVERSITY AND OVERLAP AS MEASURES OF ENVIRONMENTAL QUALITY*

Richard L. Haedrich

It is argued that indices of diversity (information function  $H$ ) and overlap (percentage similarity  $PS$ ) can be used together to assess environmental quality. The method is tested using data on demersal fishes from nine Massachusetts estuaries and embayments. Annual diversity ranged from  $H$  ( $\log_e$ ) = 0.4 to 2.4, with low diversities in areas of apparent high pollution and higher diversities in areas of lesser pollution. Where annual diversity is low, little seasonal succession is reflected in a high  $PS$  from season to season; where annual diversity is high, a relatively lower  $PS$  indicates a greater degree of change. For their calculation, both  $H$  and  $PS$  require the number of individuals in each species in a sample. These data should be considered important in the conduct of faunal surveys that contribute to an environmental impact statement.

Published in: *Water Research*

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*DISTRIBUTION AND BIOMASS OF TRAWL-CAUGHT ANIMALS OFF SPANISH SAHARA, WEST AFRICA*

Richard L. Haedrich, Maurice Blackburn, Jacques Brulhet  
Collaborator: Pamela T. Polloni

The data obtained from 40 benthic trawls made during March-May 1974 in the upwelling area off Spanish Sahara were used to determine the general local distribution and biomass of the larger epibenthic animals. The mean biomass on the shelf is about 4.2 gm/m<sup>2</sup>; fishes average 2.1 gm/m<sup>2</sup> and cephalopods 0.8 gm/m<sup>2</sup>. The wide range of observations on total biomass and high standard deviations suggests a patchy distribution. The greatest catches occurred along the shelf break, where fishes, the shrimp *Plesionika*, and echinoderms had their highest abundance. Cephalopods were more abundant on the shelf than at the shelf break. The composition of the fish fauna varied with depth, with Sparidae dominant in 20-40 m, Sciaenidae, Pomadisyidae, and Congridae dominant in 60-90 m, and Caproidae dominant at the shelf break in 120-160 m. Sparidae were less abundant in May than in March and April. Compared with other regions, the epibenthic biomass is not particularly high.

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ZONATION AND FAUNAL COMPOSITION OF EPIBENTHIC POPULATIONS  
ON THE CONTINENTAL SLOPE SOUTH OF NEW ENGLAND

Richard L. Haedrich, Gilbert T. Rowe, and Pamela T. Polloni  
Collaborator: C. Hovey Clifford

The epibenthic macrofauna, including demersal fishes, between 140 and 1900 m on the continental slope south of New England was found to be distributed in three zones: shallow (141-285 m), middle (393-1095 m), and deep (1270-1928 m). Faunal boundaries were associated with the transition zones from shelf to upper continental slope and from upper to lower continental slope. The small Alvin Canyon was not faunally distinct. Fishes and echinoderms were the most abundant taxa, the former predominant in shallow and middle depths and the latter predominating deeper. The macrofauna was less diverse than the macrobenthic infauna of the same region, but the biomass of each fraction of the fauna was of the same order of magnitude.

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SELECTIVITY OF GEAR ON BROOK TROUT AND JUVENILE ATLANTIC SALMON  
IN THE MATAMEK RIVER, QUEBEC

R. John Gibson. Collaborator: Paul C. Kerkhoven

Brook trout and juvenile Atlantic salmon were caught by angling and seining, and with fyke and gill nets. The efficiency and selectivity of these methods were compared. All methods successfully caught trout. Seining selected for yearling trout at one location, where they were abundant, but not at another, where they were sparse. Angling, fyke nets and gill nets under-represented yearling trout. The 1½ in. (stretched mesh) monofilament gill nets caught proportionately more two-year-old trout at the location where the condition factor of trout was 1.2, but proportionately more three-year-old trout at the location where the condition factor was 1.0. Juvenile salmon were caught in greatest numbers by angling with flies and by weining. Fyke and gill nets caught few salmon, except in the early summer and late fall. The fyke nets gave the best representation of age structure older than fry. Seining caught proportionately more yearling salmon than older fish, whereas gill nets and angling selected for the older salmon. The catchability of trout and salmon changed considerably with season.

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THE FOOD OF BROOK TROUT AND JUVENILE ATLANTIC SALMON IN THE MATAMEK RIVER, QUEBEC

R. John Gibson. Collaborator: Paul C. Kerkhoven

Brook trout and juvenile Atlantic salmon were sampled from June to September in 1970 and 1971. Stomach volumes were greatest in June and least in August, and September. This fluctuation was more marked with trout than with salmon. A wide variety of organisms was eaten in June, and the diet of trout and salmon was most similar at this time. Towards the end of July trout co-existing with salmon moved away from rapids near a falls whereas salmon were most abundant near the falls all

summer. Trout in August relied more heavily on emerging and adult Trichoptera and more on terrestrial insects than salmon, which ate more Chironomidae and Simuliidae than trout. In September trout ate more case-bearing trichopteran larvae than salmon, which ate more net-spinning trichopteran larvae than trout. Trout upstream, where there were no salmon, ate more net-spinning trichopteran larvae than case-bearers at this time.

Supported by: *Atlantic Foundation and Woods Hole Oceanographic Institution.*

*SELECTION BY BROOK TROUT (Salvelinus fontinalis) AND JUVENILE ATLANTIC SALMON (Salmo salar) OF SHADE RELATED TO WATER DEPTH*

R. John Gibson and Geoffrey Power. Collaborator: Paul C. Kerkhoven

Salmon parr and small brook trout were observed in two stream tanks providing choices of cover. One tank was shallow (24-29 cm) and the other deep (43-50 cm). In the shallow tank brook trout occurred most frequently under shade. When salmon were the sole species, they were most frequently under shade, but were mostly away from shade in the presence of trout. This selection for shade was not evident by either species in the deep tank.

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Supported by: *Atlantic Foundation and Woods Hole Oceanographic Institution.*

*THE RELATIONSHIPS BETWEEN INVERTEBRATE DRIFT AND SALMONID POPULATIONS IN THE MATAMEK RIVER, QUEBEC*

R. John Gibson and Donald K. Galbraith. Collaborator: Paul C. Kerkhoven

The amount of daily invertebrate drift in the Matamek River varied both seasonally and down the length of the river. From June to September 1973 the volume of drift was about eight times greater in June than in August. Filter-feeding insects and planktonic crustacea were more numerous at the upstream station near a lake, than at a station 4 km downstream. Larvae of net-spinning Trichoptera were twice as abundant at the upstream station, and Simuliid larvae four times as abundant. Numbers of zooplankton closely followed changes in water level, and were highest in early summer and the fall, and were lowest in August. The salmonid biomass was at least four times greater at the upstream station than the lower one, most likely the result of a greater abundance of insect larvae suitable as food nearer the lake.

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Supported by: *Atlantic Foundation and Woods Hole Oceanographic Institution.*

*THE FECUNDITY OF BROOK TROUT IN THE MATAMEK RIVER, QUEBEC*

R. John Gibson, Paul C. Kerkhoven and Richard L. Haedrich

Brook trout were collected in the Matamek River at two locations 4 km apart, where there were differences in density and biomass of the species. Growth rates at the two locations were similar, but trout at the upstream site, where they were more numerous, had a higher mean condition factor, compared with the downstream site. There was no difference in fecundity of the two populations, but the majority of female trout matured later at the downstream site. Later maturity, plus a lower population, resulted in a lower egg potential at the downstream location. Trout in tributary streams of Matamek Lake spawned at the beginning of September, but in the river draining the lake, where the water temperature was warmer, spawning took place later, mainly at the beginning of October.

Supported by: *Atlantic Foundation and Woods Hole Oceanographic Institution.*

*ON THE MESOPELAGIC FISH FAUNAS OF SLOPE WATER, GULF STREAM,  
AND NORTHERN SARGASSO SEA*

Andrew E. Jahn and Richard H. Backus

Midwater trawl collections from north of 32°N and west of 50°W were divided on the basis of 200-meter temperature into three sets: Slope Water ( $9^{\circ} \leq T < 15^{\circ}\text{C}$ ) - 24 collections, Gulf Stream ( $15^{\circ} \leq T < 17.5^{\circ}\text{C}$ ) - 7 collections, and Northern Sargasso Sea ( $T \geq 17.5^{\circ}\text{C}$ ) - 20 collections. A percentage similarity measure shows that the fauna of the Slope Water is distinct from those of the Gulf Stream and Northern Sargasso Sea (PS = 39% and 36%, respectively) and that the Gulf Stream and Northern Sargasso Sea sets are faunistically somewhat similar (PS = 57%). In a cluster analysis, the Slope Water and Northern Sargasso Sea sets appear distinct, while the Gulf Stream collections show affinity with both these sets. Species, clustered according to their relative abundance in each collection, form groups which correspond more to the species' overall North Atlantic distribution patterns than to their relative abundance in the three sets.

Supported by: *National Science Foundation Grant GA 31365 X.*

*NOTES ON THE PELAGIC SQUALOID SHARK, Isistius brasiliensis*

Andrew E. Jahn and Richard L. Haedrich

One hundred and thirty specimens of *Isistius brasiliensis* (Quoy and Gaimard 1824), including the "Dana" material and the type specimen of *I. plutodus* Garrick and Springer 1964 were measured, and their stomach contents and reproductive systems examined. *Isistius plutodus* differs ( $p < .01$ ) from *I. brasiliensis* in 10 of 15 morphometric and meristic characters used. Teeth of the fossil *I. trituratorus* (Winker 1878), reported here from the Eocene of Africa, have shorter bases, but caps similar to those of modern *Isistius*.

*Isistius brasiliensis* is distributed circumtropically, ranging from the surface to a depth of about 1000 meters. Males mature at about 360 mm and attain a maximum length of about 400 mm. Females mature at about 390 mm and reach a maximum



of about 500 mm. The *I. plutodus* specimen is a 423 mm mature female. The uteri of *Isistius* are thickly lined with villi, suggesting these sharks are ovoviviparous.

The stomachs of 20 specimens contained squid remains, 15 (plus *I. plutodus*) contained plugs of flesh bitten from large fish, and six contained pieces of cetacean skin and blubber. *Isistius* often kills squid, but exists chiefly as a browser upon large pelagic animals.

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*SYNOPSIS OF THE BIOLOGY OF THE WHITE MARLIN Tetrapturus albidus Poey (1861)*

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

This paper is a synopsis of the biology of the white marlin *Tetrapturus albidus* Poey (1861) covering information available up to 1974. The species is discussed in terms of its

1. Identity - Nomenclature, Taxonomy and Morphology;
2. Distribution - Total, Differential, and Determinants of change;
3. Bionomics and Life History - Reproduction, Preadult phase, Adult phase, Nutrition and Growth, and Behavior;
4. Population - Structure, Abundance and Density, Natativity and Recruitment, Mortality and Morbidity, Dynamics of Population, and population in the community and the ecosystem;
5. Exploitation - Fishing Equipment, Fishing Areas, Fishing Seasons and Fishing Operations and Results;
6. Protection and Management - Regulatory Measures.

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*RESULTS OF UNITED STATES TAGGING OF ATLANTIC BILLFISHES  
JANUARY 1, 1972 - SEPTEMBER 30, 1975*

Frank J. Mather, III, John M. Mason, Jr., Chester C. Buchanan  
Collaborator: M. Dorothy Rogers

United States tagging of Atlantic billfishes since 1971 has been carried on by sport fishermen cooperating with the Woods Hole Oceanographic Institution (WHOI), and the National Marine Fisheries Service (NMFS).

Thirty-three hundred and forty-four Atlantic sailfish, *Istiophorus platypterus*, 391 blue marlin, *Makaira nigricans*, 1,445 white marlin, *Tetrapturus albidus*, and 28 broadbill swordfish, *Xiphias gladius*, were tagged between December 31, 1971, and September 30, 1975. In this period, tags were returned by various fisheries from 37 Atlantic sailfish, 4 blue marlin, 43 white marlin and 1 broadbill swordfish. The cumulative total releases and returns by species as of September 30, 1975, were as follows (releases after slash, returns before slash): Atlantic sailfish, 144/17,188, blue marlin 9/1,068, white marlin 172/10,016, and broadbill swordfish, 3/85. The return rates are 0.8, 0.8, 1.7, and 3.5 percent, respectively.

A previously-described migratory pattern for the group of white marlin which concentrates in summer off the central United States Atlantic coast was strongly supported. Times at liberty indicated a mortality rate of 30% per year for these fish, and provided further evidence of the longevity of the species. Scattered results suggest tentative migratory patterns for other groups of white marlin.

Seasonal migrations of Atlantic sailfish between southern and northern waters, and between the Gulf of Mexico and the southeastern Florida-northwestern Bahamas area have been recorded, but the overall picture remains unclear.

No conclusions can be drawn from the few returns obtained from broadbill swordfish and blue marlin.

The complete definition of subpopulations and their migratory patterns requires intensified tagging in certain areas and seasons for white marlin and Atlantic sailfish, and on an overall basis for broadbill swordfish and blue marlin.

Supported by: *National Marine Fisheries Service Contract 03-6-042-35108.*

*RESULTS OF UNITED STATES COOPERATIVE TAGGING OF ATLANTIC BLUEFIN TUNA  
OCTOBER 1974 THROUGH OCTOBER 1975*

Frank J. Mather, III, and John M. Mason, Jr.  
Collaborators: George Bell and M. Dorothy Rogers

Atlantic bluefin tuna tagging in the United States has been carried on by the Cooperative Game Fish Tagging Program of the Woods Hole Oceanographic Institution (WHOI) since 1954. Results of the past year's work of the newly-formed joint National Marine Fisheries Service (NMFS)-WHOI program and the Narragansett Sport Fisheries Marine Laboratory program of NMFS are presented as an up-date to SCRS/74/36.

Although most of the tagging of small bluefin tuna in recent years has been by WHOI personnel from purse seiners, almost all of the 1975 tagging was done from sport fishing vessels. With the 309 small and medium-sized and 31 giant bluefin tagged in the western North Atlantic in 1975 the total number of Atlantic bluefin tuna tagged by the United States exceeds 13,850.

Returns now total 2,670. The new results include 151 from smaller bluefin and six from giants. Of the school tuna recoveries three were from fish tagged at age 0 and indicate important information on the migratory cycle of the young of the year can be obtained from a concerted effort on this age group. Overall return rates for small bluefin have decreased since 1972 but there are new fishery factors possibly contributing to this. Tag shedding appears to be about 29.4%.

The recaptures of giant bluefin in the western North Atlantic continue to reflect the increased fishing pressure in this area. Four fish were tagged and recaptured off northern Massachusetts after times at large of from one to three years. One other traveled from Newfoundland to Nova Scotia being recaptured after six years at large. One new transatlantic migration from the Bahamas to Norway was recorded but this brings the total for this occurrence to only eight.

Tagging is a proven method of identifying populations, obtaining fishery data and monitoring movements of bluefin tuna. It must be continued in the western Atlantic and intensified in the eastern Atlantic and in the Mediterranean.

Supported by: *National Marine Fisheries Service Contract 03-6-042-35108.*

## BROOK TROUT PRODUCTION IN FOUR STREAMS IN THE MATANEK WATERSHED, QUEBEC

John F. O'Connor and Geoffrey Power

The production of brook trout (*Salvelinus fontinalis*) in four infertile streams on the Canadian precambrian shield was estimated to be between 14.5 and 66.4 Kg/ha/yr. This represents the range of total fish flesh elaborated in the streams as trout were the only species present. Differences between streams in production and P/B ratios arose from variations in cover and resulting total biomass and its distribution by age class. Production in the two most productive streams was felt to be controlled by food, while in the other two streams lack of suitable cover limited production.

Supported by: Atlantic Foundation/Woods Hole Oceanographic Institution Metamek Program.

SWORDFISH (*Xiphias gladius*) ATTACKS SUBMARINE ALVINEdward F. K. Zarudzki and Richard L. Haedrich  
Collaborators: W. D. Clarke, William E. Schevill

On 6 July, 1967 the DSRV *Alvin* was rammed by a 200-pound broadbill swordfish at a depth of 610 meters on the Blake Plateau. Catches on deep lines and in trawls have suggested the broadbill ranges as deep as 365 m. The *Alvin* encounter and observations from another deep submersible, *Deepstar 4000*, in the northern Gulf of Mexico during May 1967, indicate that the broadbill ranges at least to 600 m. In addition, these observations show that broadbills will tolerate water as cool as 8°C. What precipitates an unprovoked broadbill attack remains a matter of speculation.

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## SALT MARSHES AND MANGROVES

GRAZING BY *Talorchestia longicornis* ON AN ALGAL MAT IN A NEW ENGLAND SALT MARSH

David Brenner, Ivan Valiela, Charlene D. Van Raalte and Edward J. Carpenter

Grazing experiments using  $^{14}\text{C}$  and an analysis of fecal pellets and gut contents established that the gammaridean amphipod, *Talorchestia longicornis*, ingested blue-green algae on algal mats in a Massachusetts salt marsh. This grazing had a measurable effect on the lower algal mat, where the density of *T. longicornis* was high. Exclusion of amphipods resulted in increases in chlorophyll a content, carbon incorporation and nitrogen fixation. This effect was not seen on the upper mat where *T. longicornis* was less abundant. The assimilation efficiency of *T. longicornis* feeding on a diet consisting mainly of blue-green algae was surprisingly high (67%) considering the usual notion of blue-green algae as a poor quality food

for herbivores. The population of *T. longicornis* seems to be annual, with growth of the overwintered juveniles taking place in spring and early summer. Mature individuals reproduce and mortality reduces the adult population density starting in midsummer, leaving the young of the year to overwinter.

Supported by: *National Science Foundation Grant GA 43008.*

PHYSIOLOGICAL ADAPTATIONS OF MARSH ANIMALS  
TO A HYDROCARBON-POLLUTED ENVIRONMENT: A DISCUSSION

Kathryn A. Burns

The spill of about 175,000 gallons of Number 2 fuel oil near West Falmouth, Massachusetts, in Buzzards Bay in September, 1969, initially killed most marine life in heavily polluted areas. Sanders *et al.* (1972) surveyed the benthic near-shore populations eight days later and reported 95% of the bottom animals dead or dying. Similar toxic effects were seen on beaches and marshes where windrows of dead organisms accumulated immediately after the spill (Sanders, 1973). Oil was absorbed into the sediments and had long-term effects on the survival of marine organisms (Blumer and Sass, 1972; Sanders *et al.*, 1972; Michael *et al.*, 1975; Krebs *et al.*, 1975). Heavily oiled areas of marsh showed a great reduction in higher plants, macrofauna, and algal photosynthesis during 1970 (Teal, personal communication).

The incorporation of petroleum hydrocarbons into the West Falmouth salt marsh ecosystem was monitored by analyzing surface sediments, deep mud cores, organisms surviving the spill, and organisms recolonizing the polluted area (Burns, 1975c). Plants and animals in the heavily oiled areas showed the greatest mortality. Oil penetrated deep into the anoxic marsh muds where degradation is extremely slow. Analyses showed the persistence of oil in marsh sediments over the five years studied (Burns, 1975c). During this time animals had continuous exposure to petroleum hydrocarbons by eating oiled detritus and food organisms, by burrowing into the contaminated muds, and by possible direct absorption from the water when oil was released by leeching from tidal flooding, burrowing, and storm erosion of sediments. Analyses of animal tissues from the West Falmouth marsh in 1970 showed oil incorporation (Burns, 1975c). Analyses in subsequent years showed the continued uptake of petroleum by tissues of animals recolonizing the area.

Studies were begun to examine the effects of chronic oil exposure on the population structure and physiology of two marsh animals showing different abilities to tolerate the pollution. Crustaceans were very sensitive to the oil as shown by observations by Sanders *et al.* (1972) on ampeliscid amphipods and by Krebs (1973) on fiddler crabs. *Uca pugnax*, the mud fiddler, was chosen for study because of its sensitivity to the pollution and its abundance in the marsh fauna. Fish appeared less sensitive to the pollution and the marsh minnow, *Fundulus heteroclitus*, was chosen for comparison. The major aims of the studies described in this discussion were 1) to identify some physiological basis for the difference in tolerance to oil pollution in these two species and 2) to determine if these animals could withstand oil in their environment by long term behavioral, physiological, or genetic adaptations enabling them to tolerate higher levels of oil than a non-exposed population.

Supported by: *National Science Foundation Grant GA 40987.*

GROWTH, ABUNDANCE AND DISTRIBUTION OF LARVAL TABANIDS  
IN EXPERIMENTALLY FERTILIZED PLOTS ON A MASSACHUSETTS SALT MARSH

Richard Meany, Ivan Valiela, John M. Teal  
Collaborators: Suzanne B. Volkmann, Norma Y. Perrson

The coastal salt marshes of the eastern United States provide breeding habitats for several species of biting flies of the family Tabanidae. The larvae are found in the sod of the marsh where they spend up to a year or more before pupating and emerging as adults in the summer months.

A number of investigators have studied the distribution and density of larval tabanids in salt marshes but it is difficult to find quantitative data on the seasonal abundance and distribution of larval horseflies, let alone evaluate the effect of the contamination of coastal marshes with nutrient-rich waste water.

The present investigation involved intensive sampling of small areas to estimate the abundance and distribution of tabanid larvae on a salt marsh, and a study of the effect of experimental nutrient enrichment simulating eutrophication on larval tabanid populations. In addition, the feeding preferences of the larvae of *Tabanus nigrovittatus* Macquart, the major horsefly in Massachusetts marshes, and the role that cannibalism may play in regulating larval numbers and distribution were investigated.

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EFFECTS OF NUTRIENT ENRICHMENT ON A MANGROVE ECOSYSTEM: HERBIVORES

Christopher P. Onuf, Ivan Valiela, John M. Teal  
Collaborators: John P. Clarner, Suzanne B. Volkmann

The response of red mangrove, *Rhizophora mangle*, to nutrient enrichment due to additions of bird guano were previously described. The leaves and fruit of the mangroves in an island used by birds as a rookery were enriched in nitrogen. Since there is evidence that nitrogen enrichment increases herbivory in terrestrial (McNeill, 1973) and marsh grasses (S. Vince, pers. comm.) we followed the response of the plant consumers on plant growth.

Supported by: *Atlantic Foundation and Harbor Branch Research Foundation.*

EFFECTS OF NUTRIENT ENRICHMENT ON A MANGROVE ECOSYSTEM:  
GROWTH OF RED MANGROVES (*Rhizophora mangle*)

Christopher P. Onuf, John M. Teal, Ivan Valiela  
Collaborators: John P. Clarner, Suzanne B. Volkmann

Mangroves are the dominant form of vegetation along 75% of the coastline between 25°N and 25°S (Golley *et al.*, 1962). In Florida the human population of this zone has grown rapidly in recent years, increasing the quantity of domestic wastes and agricultural runoff that pass through this vegetational skin of the Florida peninsula. Harm to the mangroves would reduce the export of detritus from mangroves on which organisms of the estuaries depend, (Odum, 1971) and weaken the

protection against storms that the fringe of mangroves provides. On the other hand, eutrophication would benefit mangroves, promoting more rapid growth and usable forest products.

Nutrient enrichment of mangroves, forcing changes in the rates of processes to yield a new balance, ought to expose the important relationships and bottlenecks of the mangrove ecosystem. Since nitrogen is limiting to production in shallow water marine systems (Ryther and Dunstan, 1972; Valiela and Teal, 1974; Lugo and Snedaker, 1974) we therefore looked for a source of nitrogen additions. A readily available source of enrichment of nitrogen as well as other nutrients was a bird rookery, where guano was added regularly for much of the year. Further, this provided a natural source of nutrients, affecting the amounts of materials added rather than the kinds of materials.

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*A COMPARISON OF HYDROCARBONS IN ANIMALS AND THEIR BENTHIC HABITATS*

John M. Teal and John W. Farrington. Collaborators: K. Burns, S. Volkmann, W. Sass, B. Tripp, N. Mosesman, J. Parkin, E. Robinson

Studies in several estuarine and marsh areas have shown significant differences between the composition of petroleum hydrocarbons in benthic animals and their habitat. When subjected to an oil spill some animals take up a mixture of petroleum hydrocarbons with a composition similar to that of the spilled oil found in the substratum. Others develop the ability to metabolize or otherwise modify their hydrocarbon content such that it approaches the pre-spill conditions.

When sediments are pulsed with petroleum hydrocarbons from an oil spill, degradation occurs at rates which are significantly different for different classes of compounds. Some classes persist for more than five years in significantly elevated concentrations. In contrast, biogenic hydrocarbons in relatively unpolluted sediments seem to be subjected to little degradation over 10 to 50-year periods after deposition.

Supported by: *Environmental Protection Agency (EPA) Grant R802724 and Victoria Foundation.*

*PRODUCTION AND DYNAMICS OF EXPERIMENTALLY ENRICHED SALT MARSH VEGETATION: BELOW-GROUND BIOMASS*

Ivan Valiela, John M. Teal and Norma Y. Perrson  
Collaborators: Susan Volkmann and Margaret Strumski

Root growth increased during the early growing season in *Spartina alterniflora* salt marsh plots. While fertilization with nitrogenous fertilizer did not affect initial growth, a marked decrease in root biomass followed the spring peak particularly where nutrient doses were highest. A sharp reduction in roots occurred in enriched areas covered by *S. patens*, although, as with *S. alterniflora*, above-ground biomass increased. Roots disappeared during autumn leaving rhizomes as the only part of the plants to overwinter. The maximum standing crop for roots was 0-2cm deep, for rhizomes 2-5cm. Net annual underground production was calculated from annual increments in dead matter belowground. Total production, underground

and above ground, exceeds that of any marine vegetation, ranging from 3900 to 6600 g/m<sup>2</sup>/yr in *S.alterniflora* areas and 3200 to 6200 g/m<sup>2</sup>/yr in *S.patens* areas. Fertilization, whether with sewage sludge or not, increased production particularly above ground where dead plant parts are subject to export.

Supported by: *the Victoria Foundation.*

*PRODUCTION AND DYNAMICS OF SALT MARSH VEGETATION AND THE EFFECTS  
OF EXPERIMENTAL TREATMENT WITH SEWAGE SLUDGE*

Ivan Valiela, John M. Teal and Warren J. Sass  
Collaborator: Norma Y. Persson

(1) Fertilization with a 10-6-4 sewage sludge fertilizer increased the total peak standing crops of salt marsh vegetation, in spite of the presence of considerable amounts of heavy metals and chlorinated hydrocarbons in the sludge.

(2) Increases in standing crop were detected in the second year of treatment and remained for three years of treatment. The increases in biomass are believed to be due to the nitrogen additions.

(3) *Spartina alterniflora*, which was the dominant species in low marsh areas, progressively excluded *Salicornia* spp. from the fertilized plots after an initial increase of *Salicornia*. In high marsh areas, fertilization initiated the standing crop of *Distichlis spicata* but this was later replaced by *Spartina patens*. *S. alterniflora* did not respond to fertilization in the high marsh.

(4) The amount of dead matter in both high and low marsh was highest in the fall after death of the sward and decreased slowly to a low point in midsummer. The amount of dead matter was never equal to peak live biomass, implying decomposition or tidal export.

(5) The production achieved by the most heavily fertilized plots are among the highest recorded for marsh plants, except in exceptionally favourable sites of tall form *S. alterniflora*.

(6) Our treatments have converted low marsh vegetation consisting mainly of dwarf form *S. alterniflora* into a sward approaching the biomass and morphology of tall form. We conclude that the so-called 'forms' are a response to nitrogen supply.

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*ASSIMILATION OF SEWAGE BY WETLANDS*

Ivan Valiela, Susan Vince, John M. Teal

Ecological features allow wetlands to retain a variety of contaminants: nutrients, heavy metals, chlorinated and petroleum hydrocarbons. This review takes up in turn each of these broad categories of contaminants, and illustrates how the properties of wetlands outlined operate in relation to selected chemical species. A last section discusses the effect of wetlands on bacteria and viruses in contaminated waters.

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EPIBENTHIC SALT MARSH ALGAE: LIGHT AND NUTRIENT LIMITATION

Charlene D. Van Raalte, Ivan Valiela and John M. Teal  
 Collaborators: John P. Clarner, Norma Y. Persson, Nathaniel Corwin

Epibenthic algal production was measured in Great Sippewissett marsh, Falmouth, Massachusetts, in plots treated with two levels of a mixed fertilizer and with urea or phosphate. Production followed a seasonal pattern with short-lived peaks occurring in the spring and fall. The highest dosage of mixed fertilizer increased production but no clear response was seen in the other treatments.

Limitation of algal production by light occurred at the marsh surface due to shading by the grass canopy. The production rate decreased with increasing biomass of the marsh grasses.

Since fertilization increased production of the grasses, the effects of light and nutrients were confounded in the treated areas. In order to separate these two factors, additional small plots were enriched with three levels of nitrogen (suspected as the limiting nutrient) and provided with three levels of canopy cover cross-classified to the nitrogen treatments. Both shading by the grasses and fertilization with nitrogen significantly affected production.

When the grasses were dormant, prediction from a model of epibenthic production based on limitation by light compared well with observed measurements. The predicted production rate was higher than that observed during the growing season of the grasses. In the plots receiving the highest doses of mixed fertilizer, the added nutrients compensated for the light limitation since the discrepancy between predicted and observed values was smaller than in the control plots.

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PREDATION BY THE SALT MARSH KILLIFISH *Fundulus heteroclitus* (L.) IN RELATION TO PREY SIZE AND HABITAT STRUCTURE: CONSEQUENCES FOR PREY DISTRIBUTION AND ABUNDANCE

Susan Vince, Ivan Valiela, Nell Backus and John M. Teal  
 Collaborators: Norma Y. Persson, Suzanne B. Volkmann

1. Laboratory feeding preference experiments demonstrated that the maximum size of prey eaten (the small *Melampus bidentatus* and the amphipod *Orchestia grillus*) increases with increasing size of the predator, *Fundulus heteroclitus*. *Melampus* larger than 7 mm in shell height escape predation by even the largest killifish.
2. Low marsh has few stems per unit area, while high marsh is considerably more complex, with many small stems closely set together.
3. Consumption of prey is reduced in high marsh relative to low marsh, particularly in the case of larger fish. This is probably due to the effect of habitat structure on hunting behavior by the fish and in providing cover for prey.
4. The population of *Melampus* in low marsh within Great Sippewissett salt marsh consists mainly of large snails, while this size is rare in high marsh. The reverse size distribution exists for *Orchestia*, where large amphipods are more abundant in high marsh.
5. Construction of fences excluding *Fundulus* from the marsh surface led to low marsh size distributions of *Melampus* and *Orchestia* resembling those of high marsh, in agreement with the laboratory results.



6. Killifish predation seems to be an important factor regulating the abundance and size distribution of the two prey species in the two marsh habitats.

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## PHYSIOLOGY

### *HYDROCARBON METABOLISM IN THE INTERTIDAL FIDDLER CRAB*

Kathryn A. Burns

The fiddler crab, *Uca pugnax*, was examined for its ability to metabolize foreign hydrocarbons. The microsomal mixed function oxidase system was identified in *Uca* tissues using Aldrin epoxidation rates as the assay. Rates were slow: 96 pmoles Dieldrin per mg microsomal protein in one hour in hepatopancreas, 438 pm  $\text{mg}^{-1} \text{hr}^{-1}$  in gill, and 228 pm  $\text{mg}^{-1} \text{hr}^{-1}$  in claw muscle microsomes. No difference in rates could be detected in animals living in clear areas or environments highly contaminated with foreign hydrocarbons. *In vivo* rates of naphthalene oxidation were measured and used to calculate a clearance time for *Uca* body tissues based on the hydrocarbon content of crabs collected from an oil polluted salt marsh.

Supported by: *National Science Foundation Grant GA 40987.*

### *ENVIRONMENTAL CONTAMINATION AND THE INDUCTION OF MICROSOMAL MIXED FUNCTION OXIDASES IN AN ESTUARINE FISH, Fundulus heteroclitus.*

Kathryn A. Burns and Dennis J. Sabo

An hepatic microsomal mixed function oxidase (MFO) system is described in the estuarine fish, *Fundulus heteroclitus*. *In vitro* aldrin epoxidation rates were measured and compared favorably to those seen in freshwater fish. The oxidases are microsomal, require NADPH, and contain cytochrome P-450. The system is completely inhibited by carbon monoxide. The introduction of 100 ppb sodium phenylbutazone to holding tanks increased aldrin epoxidation rates 3-fold, cytochrome P-450 levels 10-fold, and liver microsomal protein 2-fold when compared to control fish. Rates of aldrin epoxidation in fish living in salt marshes contaminated with petroleum derived and chlorinated hydrocarbons were generally twice those seen in populations living in a clean environment. The calculated Michaelis constants ( $K_m$ ) and maximum velocities ( $V_{max}$ ) were  $4.5 \times 10^{-6}$  M and 0.26 nmoles dieldrin formed/mg microsomal protein min in fish living in a clean area and  $6.5 \times 10^{-6}$  M and 0.93 nm/mg min in fish from an oil polluted environment. These results are consistent with the hypothesis that environmental contamination induces high levels of MFO in fish.

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*EFFECT OF PRESSURE ON THE ABSORPTION SPECTRUM OF SOME HEME COMPOUNDS*

Francis G. Carey and Quentin H. Gibson

Increased hydrostatic pressure shifts the spectra of several derivatives of menhaden hemoglobin towards longer wavelengths, producing a difference spectrum similar to that described by Adams and Schuster (Biochem. Biophys. Res. Commun. 58, 525). The effect requires the protein, but is similar for the R and T-forms of both liganded and deoxyhemoglobins.

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*SOME METABOLIC EFFECTS OF PETROLEUM HYDROCARBONS IN MARINE FISH*

Dennis J. Sabo and John J. Stegeman  
Collaborators: Leonard S. Gottlieb and A. Walltrom

Using *in vitro* incubation methods of fish livers (*Fundulus heteroclitus*) to study the effects of sublethal levels of petroleum hydrocarbons we have found subtle biochemical changes in carbohydrate and lipid metabolism. Fish taken from a contaminated and a clean marsh were compared to fish experimentally exposed to oil in the laboratory. Results were comparable in that total lipid synthesized from glucose was minimally affected by contamination as compared to acetate which showed an increased rate of incorporation. However, when the total lipid fraction was separated by thin layer chromatography there was a significant decrease in the amount of phospholipid synthesized from all three substrates and a decrease in triglyceride in the fish from contaminated waters. These data, together with electron microscopic observations strongly suggest that petroleum hydrocarbon contamination has an apparent effect on membrane structure and function.

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*PETROLEUM HYDROCARBON POLLUTION AND HEPATIC LIPOGENESIS  
IN THE MARINE FISH *Fundulus heteroclitus*.*

Dennis J. Sabo, John J. Stegeman, Leonard S. Gottlieb

Hepatic lipogenesis from glucose-1-C<sup>14</sup>, glucose-6-C<sup>14</sup> and acetate-1-C<sup>14</sup> in liver slices obtained from field populations of *Fundulus* living in oil contaminated waters was compared to those taken from an uncontaminated control area. Livers from contaminated fish synthesized approximately six times more lipid from glucose-1-C<sup>14</sup> when compared to control animals. The reverse was observed when glucose-6-C<sup>14</sup> was the substrate. Acetate-1-C<sup>14</sup> was metabolized equally in both groups. Liver glucose-6-phosphate dehydrogenase activity was elevated in homogenates from contaminated fish. Electron microscopic examination of livers from contaminated fish

demonstrated proliferation of the rough endoplasmic reticulum, decreased glycogen and lipid stores, and an increase in free ribosomes. The results suggest that in *Fundulus* environmental petroleum hydrocarbons stimulate lipolysis through aerobic glycolysis, depress anaerobic glycolysis and increase utilization of energy stores.

Published in: *Federation Proceedings*, 1975.

Supported by: *National Oceanic and Atmospheric Administration Sea Grant 04-4-158-8*.

#### UPTAKE AND RELEASE OF PETROLEUM HYDROCARBONS FOR MARINE ORGANISMS

John J. Stegeman and Dennis J. Sabo

Prolonged exposure of 106 ppb of No.2 fuel oil to oysters demonstrated that hydrocarbons are accumulated and are derived from the petroleum hydrocarbons in the surrounding water.

Incubating fish (scup) liver slices *in vitro* with 10 ppb No.2 fuel oil affected the metabolism of this tissue. The uptake of glucose was slightly inhibited while the metabolism of acetate was strongly inhibited relative to control values.

These results suggest a partitioning of hydrocarbons between water and tissue and/or membrane lipids as a mechanism through which hydrocarbons gain entry into the cell and affect its metabolism.

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### MARINE BIOACOUSTICS

#### COMPUTER MEASUREMENT OF BIOLOGICAL SOUND SOURCE LOCATIONS FROM FOUR-HYDROPHONE ARRAY DATA

William A. Watkins. Collaborator: Teresa Bray

The measurement of sound arrival times at the hydrophones of a three-dimensional array has been the difficult part of the analysis for biological acoustic source location. The development of a system that relegates these signal comparisons and measurements to computer analysis is described. The essential steps which require human judgment are retained allowing a flexible analytic procedure that requires less time, has greater accuracy, and less operator bias than manual measurements.

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A PROBABLE SIGHTING OF A LIVE *Tasmacetus shepherdi* IN NEW ZEALAND WATERS

William A. Watkins

A five meter whale was observed from a bluff near Summer, New Zealand, on 28 November, 1964, that matches the description recently published by Mead and Payne (*Jour.Mamm.* 56: 213-218) of a stranded specimen of *Tasmacetus shepherdi*. Of the seven records of this whale to date, this is the only live *Tasmacetus* that has been reported.

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SPERM WHALES (*Physeter catodon*) REACT TO PINGERS

William A. Watkins and William E. Schevill. Collaborators: Denise Franklin, Robert Campenot, Andrew Jahn, Richard H. Backus and William C. Cummings

Sperm whales, *Physeter catodon*, temporarily interrupted their own sound production in reaction to underwater pulses produced by our calibration sound sources (pingers). All seven whales that passed close to the hydrophone array at different times reacted the same way. They remained silent for at least two minutes, and some of the more distant ones quieted for shorter periods. Acoustic tracking of the sounds indicated that these whales moved underwater at a speed of about two knots and downward at a slope of 10-15°, in the general direction of other clicking sperm whales.

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PAINT MARKING OF PORPOISES

William A. Watkins and William E. Schevill. Collaborator: Teresa Bray

Marking with paint is suggested for short-term identification of individual cetaceans at sea, using paints that adhere to wet skin and set underwater. A suitable device for marking at sea uses a high volume valve with a short nozzle to direct a coherent stream of paint from small pressurized cans. Paints were tested under a variety of conditions and a captive *Tursiops* was marked. The duration of the paint on smooth skin was less than 24 hours; its removal was apparently caused by the naturally rapid sloughing of epidermal cells.

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RIGHT WHALE FEEDING AND BALEEN RATTLE

William A. Watkins and William E. Schevill.

Surface and subsurface feeding behavior of right whales, *Eubalaena glacialis* (Borowski, 1781), has been observed in Cape Cod waters since 1956. During surface feeding the whales follow discrete rows of concentrated plankton, and in subsurface

feeding they also appear to be feeding on specific patches of food at particular depths and localities. No purposeful underwater sounds are heard during feeding, but the rattle of baleen is often audible during surface feeding and appears to be an adventitious sound. The baleen rattles only when it is held so that some of the forward plates are out of the water while others are partly immersed and subject to movement by passing waves. The rattle is a low level, highly variable sound, composed of sporadic sequences of two to ten broad bandwidth pulses at uneven repetition rates and widely varying levels. Dominant frequencies are usually between two and four kHz.

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# CHEMISTRY

C-1

DEPARTMENT OF CHEMISTRY  
Derek W. Spencer, Chairman

## GEOCHEMISTRY

## PETROLOGY AND GEOCHEMISTRY OF BASEMENT ROCKS RECOVERED ON LEG 37, DSDP

Wilfred B. Bryan, Geoffrey Thompson, Frederick A. Frey,  
John S. Dickey, Jr., Stephen Roy

Petrography, mineral analyses, and bulk major and trace element analyses are presented for selected samples from sites 332A, 332B, 333A, 334 and 335 of DSDP (Deep Sea Drilling Project) Leg 37 in the North Atlantic at about 37°N latitude.

Petrographic observations were made on small polished thin sections or on glass chips which also served as mounts for microprobe analyses. Our major petrographic emphasis was on microphenocrysts and skeletal quench phases in glasses and microphenocrysts in crystalline samples as these are considered to be most diagnostic of magma composition.

Natural glass and mineral compositions were determined directly by electron microprobe analysis. Bulk major element analyses of crystalline samples were determined by microprobe analysis of fluxed glasses. Trace elements were determined by emission spectrometry and neutron activation. These methods, their precision and accuracy, were discussed by Frey *et al.* (1974). Four of the analyzed samples from Leg 37 are powders selected for interlaboratory comparison purposes; these samples are indicated in our data tabulations. Sample 335-8-3, 98-101, a natural glass, was analyzed directly by microprobe and also as a fluxed glass; agreement of the analyses is good. The precision of the trace element analyses can be estimated by comparing data for fresh and weathered portions of the same samples, or repetitive analyses of certain core splits, e.g. 333A-3-1, 74-77 and 333A-3-1, 75-76.

Where fresh and weathered portions of samples have been analyzed, alteration has caused an increase in H<sub>2</sub>O, Fe<sub>2</sub>O<sub>3</sub>/FeO, K<sub>2</sub>O, B and Li. Other element abundances are unaffected and thus these elements are useful for petrologic interpretations. Weathered portions containing carbonate-rich areas have been avoided; our data indicate that samples with appreciable carbonate (>5% CO<sub>2</sub>) show an increase in Ca and Sr but other elements are only "diluted" by the calcite matrix.

The chemical and mineral analyses are presented separately in the appropriate site reports. In addition to the DSDP sample numbering system we have identified each sample according to the shipboard-defined lithologic and chemical unit. In this report we briefly summarize and interpret our observations and data.

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*EASTERN INDIAN OCEAN DSDP SITES: CORRELATIONS BETWEEN PETROGRAPHY,  
GEOCHEMISTRY AND TECTONIC SETTING*

Frederick A. Frey, John S. Dickey, Jr., Geoffrey Thompson, Wilfred B. Bryan

At 10 of 13 Deep Sea Drilling Project sites in the eastern Indian Ocean, there is a correlation between inferred tectonic history and the petrographic and geochemical nature of basement basalts. Compositions of unaltered glasses and phenocrysts, in addition to abundances of Ti, Zr, and rare-earths, are used to determine the geochemical characteristics of magmas erupted at each site. At sites 212, 213,



257, 259, 260 and 261, the basalts are within the compositional range of large ion lithophile (LIL) element depleted tholeiites dredged from spreading ridge axes, such as the Mid-Indian Ocean Ridge. These results are consistent with tectonic models indicating a seafloor spreading origin for basement basalt at these sites. In contrast, the alkali-olivine basalts at site 211 are probably related to volcanism creating the nearby Cocos, Keeling, and Christmas Islands.

Rocks from the aseismic Ninetyeast Ridge (sites 214, 216 and 254) are LIL element enriched tholeiites, ferrotholeiites and oceanic andesites. Similar suites occur on oceanic islands such as Iceland, Galapagos, Faeroes and the St. Pauls-Amsterdam complex in the Indian Ocean. The geochemical features of these Ninetyeast Ridge rocks therefore imply a petrogenesis similar to that of tholeiitic island sequences. This conclusion is consistent with tectonic models relating portions of the Ninetyeast Ridge to a hot spot trace.

Inconsistencies between tectonic models and magma geochemistry occur at sites 253, 215 and 256. The occurrence of LIL element depleted tholeiite at site 253 on the Ninetyeast Ridge is anomalous and unexplained. Equally surprising are the high LIL element abundances of tholeiitic basalts at site 215. These basalts are similar in composition to a basalt dredged from a seamount flank in the northeast Indian Ocean, but they are distinctly different from Ninetyeast Ridge basalts. There are no anomalous bathymetric features at site 215, but the unexpectedly young, inferred basement age and the atypical composition imply that site 215 basalts were not formed at a spreading ridge axis. At site 256, LIL element-enriched ferrotholeiites are also unlike basalts formed at spreading ridge axes. These basalts may be related to the volcanism creating the northeasterly trend of topographic highs extending from Broken Ridge through site 256.

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#### ELEMENTAL FLUXES DURING HYDROTHERMAL ALTERATION OF BASALTS

Susan E. Humphris

The alteration of basalts during hydrothermal circulation at the mid-ocean ridges provides a mechanism for elemental exchange between seawater and igneous rock. Major and trace element analyses of the core-to-rim compositional changes have been carried out on hydrothermally altered basalts from the Mid-Atlantic Ridge. Two distinct classes of metabasalt are recognized. Both show significant loss of Si and Ca, and uptake of Mg and H<sub>2</sub>O. One class is probably indicative of reaction with seawater under reducing conditions. The most altered regions are characterized by an increase in total iron and Fe<sup>2+</sup>/Fe<sup>3+</sup> ratio, and a loss of sodium. Chlorite is the dominant alteration product in these samples with some albite, actinolite and pyrite, and occasionally epidote present. The second class is characterized by a decrease in total iron and Fe<sup>2+</sup>/Fe<sup>3+</sup> ratio in the altered regions. Na is gained during alteration of these samples which are albite-actinolite-chlorite-epidote assemblages.

Mass balance calculations, in conjunction with existing geophysical data, suggest these reactions produce significant geochemical fluxes for some of the elements, and may be important in the controls on the chemical composition of seawater.

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*METALLIFEROUS DEPOSITS ON THE MID-ATLANTIC RIDGE*

Geoffrey Thompson, C. C. Woo and W. Sung

A number of large boulders (up to 1 kg) of black, crystalline manganese-rich rocks have been recovered from the flanks of the Mid-Atlantic Ridge (MAR) about 60 km from the spreading axis at 23°N latitude. These rocks, dredged from a fault scarp in association with basalts, are almost pure manganese oxide in the form of the mineral todorokite. Typically they have a Fe/Mn ratio of  $7 \times 10^{-4}$ , and Cu is the only other transition metal present in appreciable ( $> 0.1\%$  wt.) amounts.

A similar, but less massive manganese-rich deposit has also been recovered by the French submersible from the FAMOUS region at 36°N near the MAR axis. Of the two samples we have studied from this region, one is birnessite; the other is todorokite. They are found as encrustations on Fe and Mg-rich smectites recovered from a circular, mound-like deposit in a fracture zone associated with high heat flow. Chemically they are similar to the todorokite boulders at 23°N, although containing less Cu, Sr and Ba.

These two new occurrences are compared with the birnessite deposits recovered from the Trans-Atlantic Geotraverse (TAG) area in the median valley of the MAR at 26°N. An origin by precipitation from hydrothermal solutions emanating from the ocean floor is postulated for all three occurrences of Mn-oxide.

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*INFERRED GEOLOGIC SETTINGS AND DIFFERENTIATION IN BASALTS  
FROM THE DEEP SEA DRILLING PROGRAM*

Wilfred B. Bryan, Geoffrey Thompson, Frederick A. Frey and John S. Dickey

Petrographic and geochemical studies of basalt glass and related rocks from the Deep Sea Drilling Program (DSDP) provide a random sampling of magmas which have crystallized to form the sea floor basement rocks. The samples range in age from 155 m.y. to less than 4 m.y. and represent a variety of geologic settings within the three major ocean basins. The majority, from oldest to youngest, show the mineralogy, textures, and large ion lithophile (LIL)-element depleted characteristics of modern basalts from mid-ocean spreading ridges (Group I). A smaller but compositionally diverse group shows distinctive mineralogy and LIL-element enrichment (Group II). Group II magmas from spreading ridges are apparently identical to Group I magmas in terms of major element variations. Group II magmas from seamounts and off-ridge centers tend to be olivine-normative and enriched in normative plagioclase, while those from aseismic ridges tend to be iron-enriched and quartz normative.

The diversity represented among DSDP rocks as a whole is only slightly greater than that shown at a single well-sampled Mid-Atlantic Ridge site (FAMOUS). There are a few unusually Fe- or Ti-rich samples which so far are unique to the Pacific and Indian Oceans. Compositional diversity in the Indian Ocean is especially striking.

Preliminary petrogenetic modeling suggests that the samples as a whole are not products of a single high-level fractionation sequence. Glasses which project

on a pseudo-binary cotectic in the Di-An-Fo system may differ significantly in FeO/MgO, TiO, and LIL-element enrichment at comparable points on the cotectic. These liquids probably represent a mixture of mantle-derived partial melts and their fractionation products. Within the data set individual fractionation sequences can be defined, in which most major elements are adequately explained by simple crystal-melt equilibria. However, even in these sequences inferred residual liquids tend to show excess LIL-element enrichment which is not yet understood.

Most DSDP basement rocks can be related back to a spreading ridge environment if due account is taken of apparent "plume-related" geochemical variations along modern ridges. Unusual LIL-enriched sea floor not otherwise explained may be related to areas such as that at 45°N, where there is little evidence of structural or bathymetric anomalies associated with a "plume". We see no persuasive evidence for geochemical or mineralogical features diagnostic of variations in spreading rate, nor is there any obvious relation between composition and age.

Supported by: *National Science Foundation Grant DES 74-00268.*

*CHEMISTRY OF FERROMANGANOAN SEDIMENT OF THE BAUER DEEP*

Frederick L. Sayles, T-L. Ku, and Paul C. Bowker

Sediment from the Bauer Deep in the east Pacific is commonly carbonate free, containing only small amounts of detrital minerals, and is enriched in Fe, Mn, Cu, Co, Ni, Zn, and Ba. An Fe-montmorillonite and ferromanganese compounds, occurring both as colloids and micronodules, are the principal phases present. A large proportion of the Fe occurs in the Fe montmorillonite, which appears to originate from the interaction of hydrothermal solutions with sea water. Adsorption and incorporation of metals from sea water on the micronodules or the Fe and Mn oxide colloids, best explain the elemental relationships observed for Fe, Mn, Cu, Zn, and Ni in the oxide fraction of the sediment. These processes are responsible for the enrichment of the sediment in Ni, Co, and possibly Mn. Enrichment in Cu and Zn occurs in both the oxides and the Fe montmorillonite.

Sedimentation rates measured in one core provide a minimum value of 2.5mm/10<sup>3</sup>yr. The rate of accumulation of authigenic material is more than 2 mm/10<sup>3</sup>yr. Elemental accumulation rates of Fe, Mn, Cu, Ni, and Zn are comparable to those found near the crest of the East Pacific Rise.

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*INTERSTITIAL SOLUTIONS AND DIAGENESIS IN DEEPLY BURIED MARINE SEDIMENTS;  
RESULTS FROM THE DEEP SEA DRILLING PROJECT*

Frederick L. Sayles and Frank T. Manheim

Through the Deep Sea Drilling Project samples of interstitial solutions of deeply buried marine sediments throughout the World Ocean have been obtained and analyzed. The studies have shown that in all but the most slowly deposited sediments pore fluids exhibit changes in composition upon burial. These changes can be grouped into a few consistent patterns that facilitate identification of the diagenetic reactions occurring in the sediments.

Pelagic clays and slowly deposited ( $<1$  cm/ $10^3$ yr) biogenic sediments are the only types that exhibit little evidence of reaction in the pore waters.

In most biogenic sediments sea water undergoes considerable alteration. In sediments deposited at rates up to a few cm/ $10^3$ yr the changes chiefly involve gains of  $\text{Ca}^{2+}$  and  $\text{Sr}^{2+}$  and losses of  $\text{Mg}^{2+}$  which balance the  $\text{Ca}^{2+}$  enrichment. The Ca-Mg substitution may often reach 30 mM/kg while  $\text{Sr}^{2+}$  may be enriched 15-fold over sea water. These changes reflect recrystallization of biogenic calcite and the substitution of  $\text{Mg}^{2+}$  for  $\text{Ca}^{2+}$  during this reaction. The Ca-Mg carbonate formed is most likely a dolomitic phase. A related but more complex pattern is found in carbonate sediments deposited at somewhat greater rates.  $\text{Ca}^{2+}$  and  $\text{Sr}^{2+}$  enrichment is again characteristic, but  $\text{Mg}^{2+}$  losses exceed  $\text{Ca}^{2+}$  gains with the excess being balanced by  $\text{SO}_4^{2-}$  losses. The data indicate that the reactions are similar to those noted above, except that the  $\text{Ca}^{2+}$  released is not kept in solution but is precipitated by the  $\text{HCO}_3^-$  produced in  $\text{SO}_4^{2-}$  reduction. In both these types of pore waters  $\text{Na}^+$  is usually conservative, but  $\text{K}^+$  depletions are frequent.

In several partly consolidated sediment sections approaching igneous basement contact, very marked interstitial calcium enrichment has been found (to 5.5 g/kg). These phenomena are marked by pronounced depletion in  $\text{Na}^+$ , Si and  $\text{CO}_2$ , and slight enhancement in  $\text{Cl}^-$ . The changes are attributed to exchange of  $\text{Na}^+$  for  $\text{Ca}^{2+}$  in silicate minerals forming from submarine weathering of igneous rocks such as basalts. Water is also consumed in these reactions, accounting for minor increases in total interstitial salinity.

Terrigenous, organic-rich sediments deposited rapidly along continental margins also exhibit significant evidences of alteration. Microbial reactions involving organic matter lead to complete removal of  $\text{SO}_4^{2-}$ , strong  $\text{HCO}_3^-$  enrichment, formation of  $\text{NH}_4^+$ , and methane synthesis from  $\text{H}_2$  and  $\text{CO}_2$  once  $\text{SO}_4^{2-}$  is eliminated.  $\text{K}^+$  and often  $\text{Na}^+$  (slightly) are depleted in the interstitial waters.  $\text{Ca}^{2+}$  depletion may occur owing to precipitation of  $\text{CaCO}_3$ . In most cases interstitial  $\text{Cl}^-$  remains relatively constant, but increases are noted over evaporitic strata, and decreases in interstitial  $\text{Cl}^-$  are observed in some sediments adjacent to continents.

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GEOCHEMISTRY AND PETROLOGY OF BASALTIC AND GABBROIC ROCKS FROM THE  
FRACTURE ZONE AND ADJACENT RIDGE CRESTS OF THE MID-ATLANTIC RIDGE AT 22°S.

Beverly M. Carroll

The variations in the compositions of the 22°S basalts are due to equilibrium crystallization of very similar parental magmas at approximately 40km depth followed by separation of the melt from all the precipitated crystals except small amounts of plagioclase which are brought to the surface with the magma. Olivine and some plagioclase are crystallized and lost from the magma during ascent.

Chromian spinel is not believed to have crystallized at depth. It apparently is stabilized by crystallization of olivine at low pressures. The spinel show systematic trends in composition similar to those observed in some ultramafic rocks but the causes of the trends are as yet uncertain.

The Gabbros and ferro-diorites from the fracture zone are cumulates formed in intrusions of basaltic magma that crystallized between 10 and 40 km depth. Fractionation in such intrusions can be extreme with the final liquid formed crystallizing as a quartz-albite aplite.

The igneous processes north of, within, and south of the fracture zone appear to be identical. The apparent degree of greater fractionation in the fracture zone rocks is most likely due to the lack of deep crustal samples from locations other than fracture zones. The parallel ridges in the fracture zone appear to be slices from the adjacent plates that have been elevated to their present positions.

The similarities in the compositions of the basalts throughout the area indicate that the basalts are all derived from mantle material that has very similar compositions and that has undergone very similar amounts of partial melting.

Supported by: *National Science Foundation Grant DES 74-22971.*

## ORGANIC AND BIOCHEMISTRY

### *INVESTIGATIONS OF SEAWATER AND TERRESTRIAL HUMIC SUBSTANCES WITH CARBON-13 AND PROTON NUCLEAR MAGNETIC RESONANCE*

Daniel H. Stuermer and James R. Payne

Seawater and terrestrial fulvic acid are investigated with carbon-13 and proton nuclear magnetic resonance and by infrared spectroscopy. These data provide structural information and comparison of structural features between humic substances from seawater and terrestrial origin.

Seawater fulvic acid is much more aliphatic and less aromatic than terrestrial fulvic acid. New evidence is presented for the presence of polyhydroxyl moieties in fulvic acids from both environments. Carbonyl groups in the fulvic acid are present mainly as esters, acids or amides, not as aldehydes and ketones.

The structural differences observed seem to mainly result from the low abundance of aromatic precursors (i.e. lignin) in seawater as compared to the terrestrial environment.

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### *A DETAILED VERTICAL PROFILE OF STEROLS IN THE SARGASSO SEA*

Robert B. Gagosian

Seawater samples from the Sargasso Sea have been analyzed for a class of biogenic compounds, the sterols. The profiles constructed from this data are some of the most detailed vertical profiles reported for any organic constituent in seawater. Some sterols were found in the entire water column, e.g. cholesterol, whereas others, e.g. brassicasterol, appear to be produced and consumed in the upper 1000 m of the ocean. The sterols found in the euphotic zone have short residence times, whereas the sterols found in the bottom waters may be examples of more resistant organic compounds.

Several mechanisms can be postulated for the injection of sterols into the deep sea. Vertical fluxes of organic particles from the surface appear to be the controlling factors delivering sterols into the mid-depth waters of the Sargasso Sea. However, some other process, e.g. physical transport (viz. horizontal and vertical advection and diffusion), resuspension of sediments, or *in situ* deep water biological production and consumption, is controlling deep water sterol distributions. The results reported here indicate that in order to discern the transport mechanisms of organic compounds to the deep sea, detailed profiles of ancillary data such as POC (Particulate Organic Carbon), hydrographic and total particulate matter collected at the same station are necessary to complement detailed profiles of the specific organic compounds.

Supported by: *National Science Foundation Grant DES 74-09991.*

#### STEROLS IN THE WESTERN NORTH ATLANTIC OCEAN

Robert B. Gagosian

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  $\mu\text{g}/\text{l}$  seawater. Isolation and structural elucidation by gas chromatography and combined gas chromatography-mass spectrometry show that cholesterol and  $\beta$ -sitosterol (or clionasterol) are the major free sterols in both the surface and deep water. Fucosterol, brassicasterol, 22-dehydrocholesterol, campesterol for 22.23-dihydrobrassicasterol), 22-methylenecholesterol, norcholestadienol, and stigmasterol (or poriferasterol) 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 may contribute. 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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#### CURTISITE, IDRIALITE AND PENDLETONITE, POLYCYCLIC AROMATIC HYDROCARBON MINERALS: THEIR COMPOSITION AND ORIGIN

Max Blumer

The rare polycyclic aromatic hydrocarbon minerals curtisite, pendletonite and idrialite have been analyzed by chromatography and ultraviolet- and mass-spectrometry. Pendletonite is nearly pure coronene; the other minerals contain over 30 homologous series of CH, CNS and CHN compounds, with the total number of chemical components well above one hundred. The chemistry of the contributing compounds reflects the origin of the minerals in medium temperature pyrolysis of organic

matter. The components were further modified by extended equilibration at elevated temperatures in the subsurface and by recrystallization during migration. In this last step the high-melting pendletonite achieved its exceptional purity.

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*POLYCYCLIC AROMATIC HYDROCARBONS IN THE ENVIRONMENT:  
HOMOLOGOUS SERIES IN SOILS AND RECENT MARINE SEDIMENTS*

William W. Youngblood and Max Blumer

Soils and recent marine sediments contain a complex polycyclic aromatic hydrocarbon assemblage. The many series of alkylhomologs have a similar molecular weight distribution, and it varies little over a wide range of depositional environments. It is suggested that these hydrocarbons are formed in natural fires, are dispersed and mixed by air transport and eventually deposited into surface sediments. The analytical, geochemical and environmental implications of these findings are discussed.

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*POLYCYCLIC AROMATIC HYDROCARBONS IN SOILS AND RECENT SEDIMENTS*

Max Blumer and William W. Youngblood

Soils and recent marine sediments contain a complex polycyclic aromatic hydrocarbon assemblage. There is a high degree of similarity in the molecular weight distribution of the many series of alkyl homologs of these aromatic hydrocarbons, and this distribution varies little over a wide range of depositional environments. The evidence suggests that these hydrocarbons are formed in natural fires, are dispersed and mixed by air transport, and are eventually deposited into surface sediments. The analytical, geochemical, and environmental implications of these findings are discussed.

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*POLYCYCLIC AROMATIC HYDROCARBONS - ANALYSIS OF COMPLEX MIXTURES  
BY PROBE DISTILLATION AND LOW VOLTAGE MASS SPECTROMETRY*

Max Blumer

Polycyclic aromatic hydrocarbons (PAH) are widely distributed throughout nature. Their occurrence in environmental samples is of considerable interest, geochemically, and because of the carcinogenic and mutagenic properties of many members of this class of compounds.

Simple PAH mixtures are readily analyzed by various methods, among them ultraviolet (UV) absorbance and fluorescence techniques, thin layer chromatography and gas chromatography. However, when applied to complex mixtures these simple methods are inadequate or may even suggest a simple mixture, where in fact a complex one is present. Recent work demonstrates that such complex PAH mixtures occur commonly in nature. Therefore, analytical methods of high resolving power have been developed and should be applicable to a wide range of environmental samples.

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*ORGANIC COMPOUNDS IN NATURE: LIMITS OF OUR KNOWLEDGE*

Max Blumer

Current geochemical and environmental research reveals the presence in soils and sediments of extremely complex assemblages of organic compounds. Their recognition has long been delayed by both conceptual and analytical limitations. Even today the best techniques cannot fully resolve these mixtures into their individual components. Yet, the knowledge of their structures and abundances is needed in geochemistry, and especially for the assessment of their potential biological effect and ecological impact. The classical "natural products approach" is unlikely to provide this information; therefore, I foresee the need for a more realistic assessment of nature, that acknowledges the limitations of our present analytical powers and of our knowledge.

'What we have learnt, is like a handful of Earth,  
While what we have yet to learn is like the whole World.'

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*II. HYDROCARBON STUDIES*

John M. Hunt

Eighteen core samples from Holes 259, 263, 265, 280A, 281, and 282 were analyzed for organic carbon and detailed C<sub>4</sub> to C<sub>7</sub> hydrocarbons. A total of 27 alkanes were identified in this range, the total yields ranging from 12 to 3585 parts per billion. In addition, the C<sub>15</sub><sup>+</sup> hydrocarbons and nonhydrocarbons were determined



for nine of these samples. Total C<sub>15</sub>+ hydrocarbon yields ranged from 18 to 205 parts per million. The naphthene content of the saturate fraction in all samples ranged between 80% and 90%. The organic matter in the samples is largely amorphous-sapropellic with traces of woody material. All evidence to date indicates that the C<sub>4</sub> to C<sub>7</sub> hydrocarbons are forming *in situ* from the decomposition of the organic matter.

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#### HYDROCARBONS IN THE MARINE ENVIRONMENT

John W. Farrington

The study of hydrocarbons in the marine environment is now progressing at a faster pace owing to the interest in understanding the inputs, fate, and effects of oil pollution. However, it is clear that a more complete knowledge of the hydrocarbons introduced into the marine environment by natural processes such as biosynthesis is needed.

All studies of hydrocarbons are dependent on the analytical techniques employed, and our knowledge of hydrocarbons in the marine environment was, until recently, hampered by a lack of a more widespread application of sophisticated methods of analysis. Because of their ease of analysis and their predominance in most marine samples, n-alkanes, n-alkenes, and branched alkanes have been studied to greater extent than other types of hydrocarbons. A more detailed knowledge of the cyclic and branched cyclic alkanes and naphthenoaromatic and aromatic hydrocarbons in marine samples is essential. Many of the important questions relating to oil-pollution studies and to chemical processes in surface sediments will be answered by such knowledge.

There have been significant advances in the past few years in understanding the interactions between hydrocarbons and minerals, and dissolved organic matter and hydrocarbons. These studies, when expanded and coupled with similar studies of other organic compounds in the marine environment, will provide us with a more detailed knowledge of the processes governing the distribution of organic compounds.

The chemical and biological processes acting on hydrocarbons in surface sediments are being explored. Concurrently, the role of sediment microorganisms as a source for hydrocarbons in surface sediments is being mentioned with increasing frequency. Only a few studies have demonstrated that microorganisms contribute substantially to the hydrocarbons in surface sediments. We expect that more evidence will be forthcoming in the near future. We also expect that during the next few years it will become more apparent that chemical and biological processes are operating in surface sediments and have a significant influence on which types of organic compound are found in ancient sediments.

There is a dynamic and complicated interaction between hydrocarbons in organisms and hydrocarbons in the surrounding environment. Furthermore, key studies have established a relationship between concentration and composition of hydrocarbons in organisms and the growth stage or stage of tissue development. The door to understanding the biochemical role of hydrocarbons has begun to open, with

great promise for significant advances in this area of research. Concurrently, the pathways of biosynthesis of hydrocarbons will be unravelled.

There has been a significant advance in our understanding of the physical, chemical, and biological processes affecting oil spilled into the marine environment, particularly with respect to the biodegradation of oil by microorganisms. This knowledge is far from complete, and we cannot predict with certainty the fate of any given oil spill. However, it is certain that petroleum hydrocarbons can and do linger long after visual evidence of the oil spill has disappeared.

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*GLACIAL AND PLUVIAL PERIODS: THEIR RELATIONSHIP REVEALED BY PLEISTOCENE  
SEDIMENTS OF THE RED SEA AND GULF OF ADEN*

Werner G. Deuser

Oxygen-isotope analyses of planktonic foraminifera from the Red Sea and Gulf of Aden indicate that during periods of maximum continental and polar glaciation in the late Pleistocene, the Red Sea was subject to strong evaporation. Between glacial maxima Red Sea salinity was equal to or below open-ocean salinity. This suggests that the high-latitude glacial periods corresponded in time to interpluvial stages in the present-day desert belt of northern Africa, whereas high-latitude interglacial periods coincided with pluvial stages.

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*THE BIOGEOCHEMISTRY OF PCB AND t-DDT IN THE ATLANTIC*

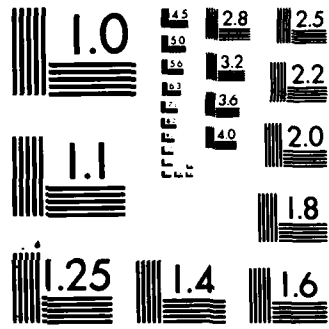
George R. Harvey and William G. Steinhauer

A. t-DDT

t-DDT is apparently very unstable in the open marine environment and probably succumbs quickly to the combined attacks of oxygen, water, sunlight and microorganisms. A small fraction of the DDT which reaches the sea surface is incorporated into the food chain where it is successively converted to the metabolite DDE by both horizontal and vertical predatory food chains. Within the body lipids of marine organisms t-DDT appears quite stable and body concentrations do not change markedly from the upper ocean organisms to the deep benthos.

Another small fraction of the DDT released into the environment reaches the sea adsorbed on particles heavy enough to fall directly to the bottom without ever entering the pelagic food chain. This appears in the deep sediments and benthos as the parent insecticide, p,p'-DDT in concentrations and ratios not seen elsewhere in the marine environment. Apparently the benthic organisms have a lower capacity for the conversion of DDT to DDE. However, in our present state of knowledge we would consider t-DDT a minor hazard to the environmental quality of the Atlantic Ocean at this time.





MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS 1963-A

## B. PCB

Commercial PCB mixtures, e.g., Aroclor, Clophen, Kanechlor, Phenochlor, contain 50-60 chlorine homologues and isomers of which about 20-30 are resolvable by gas chromatography. The vapor pressures and water solubilities of the components of these mixtures range over two orders of magnitude. However, the gas chromatographic fingerprints produced by extracts of surface sample, i.e., water, plankton, particulates, etc., are generally very good matches for the whole commercial mixtures. Thus, we must agree with Jernelov (1974) that the transfer unit of PCB to the sea must be an aerosol droplet. To quote Jernelov, "It seems quite unlikely that the "fingerprint" of the PCBs could remain the same if the individual PCB compounds evaporated to the atmosphere, precipitated to the ocean surface, and were accumulated individually in marine organisms".

Geochemically, the PCBs are quite resistant because excellent gas chromatographic fingerprints are generally observed throughout the water column and in the sediments. Biologically, they are susceptible to slow degradation. Organisms residing deep in the water column or on the bottom reveal PCB gas chromatographic fingerprints with very distorted features and missing peaks. On several occasions, the gas chromatographic match between a PCB standard and an extract of a deep living organism is so poor that quantification cannot be justified.

Since PCBs appear so resistant to geochemical degradation, they are probably capable of being transported greater distances than t-DDT by the atmosphere and by advective processes within the sea. In the North American Basin, less than 1% of the PCB introduced has been transported directly to the sediment by sinking particles. Only a very small fraction could be metabolized by organisms since only 0.1% of the PCB is accounted for in organisms. A significant fraction of the PCB introduced to the mixed layer in mid and low latitudes may be reinjected, by entrainment, codistillation, evaporation, etc., into the atmosphere and eventually deposited in the colder, low pressure trough about 60°N latitude. Finally, some portion of the PCBs must be carried to intermediate depths by fragile, soluble or edible particles which on dissolution introduce PCBs into the deep water mass. The subsequent dilution in the deep water would make concentration changes impossible to detect by current methodology.

Supported by: *National Science Foundation IDOE (International Decade of Ocean Exploration) Grant 06435.*

## SEAWATER CHEMISTRY

### *THE DISTRIBUTION OF <sup>3</sup>He IN THE WESTERN ATLANTIC OCEAN*

William J. Jenkins and W. Bryan Clarke

Over 250 samples of Atlantic seawater have been analyzed for the dissolved helium isotope ratio, and a distinctive pattern has emerged. Two components of excess <sup>3</sup>He are seen: a component due to *in situ* decay of nuclear-era tritium, and a primordial component evolved from the solid earth. A prominent feature at about three km depth can be traced from 51°N along the western boundary to the equator. The source of this feature is most probably in the Gibbs fracture zone, where we suppose that primordial <sup>3</sup>He is released into westward-flowing bottom water. The

South Atlantic profiles clearly show the effect of  $^3\text{He}$ -rich Circumpolar water, entrained by Antarctic Intermediate water flowing northward. The excess  $^3\text{He}$  in the upper 1 km, when combined with tritium concentrations measured by Östlund, Dorsey, and Rooth (1974) at the same locations and depths yields "Tritium-helium ages", which in some cases represent the time interval between equilibration with the atmosphere, and sampling.

Supported by: *National Research Council of Canada.*

*REACTION OF METHYL HALIDES WITH SEAWATER AND MARINE AEROSOLS*

Oliver C. Zafiriou. Collaborator: Charles Angevine

Methyl iodide is known to be formed biologically in seawater and has been postulated as the agent of iodine air-sea transport. Kinetic calculations and experiments demonstrate that methyl iodide reacts with chloride ion in seawater to yield methyl chloride approximately as fast as it exchanges into the atmosphere. In seawater, both methyl chloride and methyl iodide are slowly hydrolyzed to methanol and halide ions. The rate of trapping of I on sea-salt particles by reaction with atmospheric methyl iodide is shown to be too slow to account for the enrichment of the marine aerosol in I relative to seawater.

Kinetic approximations developed for this study also establish an approximate scale of relative reactivity for seawater constituents interacting with carbon compounds in second-order nucleophilic reactions:  $\text{Cl}^- > \text{HOH} > (\text{HCO}_3^- + \text{Br}^- + \text{SO}_4^{2-})$ .

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*AN OCEANIC CALCIUM PROBLEM?*

Peter G. Brewer, George T.F. Wong, Michael P. Bacon and Derek W. Spencer

Recent published data on dissolved calcium in seawater reveal an apparent excess of calcium over that predicted from the changes in alkalinity. In the South Pacific this excess calcium is approximately  $40 \mu\text{moles/kg}$ . We suggest that this arises from an *in situ* titration of some of the alkalinity by protons derived from the redox changes associated with oxidative decomposition of organic matter. This postulates an effective flux of nitric and phosphoric acids into the deep water. Other redox changes, such as in the oxidation of reduced sulfur, may also contribute protons, but these are more difficult to evaluate. This concept changes current thinking on the oceanic  $\text{CO}_2$ -carbonate system. It increases the amount of calcium carbonate believed to have dissolved in the ocean by ca. 25%; and alters the proportions of abyssal  $\text{CO}_2$  believed to be derived from respiration versus carbonate dissolution by about 10%.

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*THE DISTRIBUTION OF PARTICULATE MATTER IN THE ATLANTIC OCEAN*

Peter G. Brewer, Derek W. Spencer, Pierre E. Biscaye, Adele Hanley,  
Peter L. Sacks, Clarence L. Smith, Susan Kadar and Janet Fredericks

We have determined the dry weight of suspended particulate matter in seawater in a section through the western Atlantic Ocean from 75°N to 52°S. The concentrations, operationally defined as that weight retained on 0.6 μm and 0.4 μm pore size Nuclepore filters, contained in 1 kg of seawater, range from 5 to 300 g/kg and show readily explainable regional features. High concentrations are found in surface waters and in association with rapidly moving bottom waters in the Denmark Straits overflow and in Antarctic bottom water to 15°S. Low concentrations, <12 μg/kg, characterize the mid-water regions of the subtropical gyres. High concentrations are seen in sinking Labrador Sea water and in a plume extending at least a kilometer off the bottom at 35°-40°N where the cruise track intersects the North Atlantic gyre. It is doubtful whether this important phenomenon could be observed by any other means, and it gives a unique insight into the scale of vertical turbulent processes.

Supported by: *National Science Foundation Grant 72-06421.*

*THE DENSITY OF NORTH ATLANTIC AND NORTH PACIFIC DEEP WATERS*

Frank J. Millero, Agustin Gonzalez, Peter G. Brewer and Alvin Bradshaw

The densities of 17 samples of sea water from GEOSECS (Geochemical Ocean Section) stations 27 (North Atlantic) and 217 (North Pacific) have been measured with a vibrating flow densimeter at 25°C. The densities of the deep samples were found to be 5 ± 1.5 and 16 ± 3.6 ppm greater, for the North Atlantic and North Pacific, respectively, than predicted by the equation of state of Millero, Gonzalez and Ward (1975) derived for sea waters of constant relative composition. The results are in good agreement with the density anomalies predicted by Brewer and Bradshaw (1975) on the basis of the observed increase of dissolved silica, alkalinity and total carbon dioxide in oceanic deep waters. The application of these corrections results in an agreement with the Millero, Gonzalez and Ward (1975) equation of state to ±4 ppm.

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*MINOR ELEMENT MODELS IN COASTAL WATERS*

Peter G. Brewer and Derek W. Spencer

The concept of a trace element residence time in the ocean leads to estimates of ca. 10<sup>4</sup> years. Were this the only factor then trace element gradients would be effectively eliminated. However, some data, and simple uptake calculations, show that gradients in surface waters do occur. Attempts to evaluate this by a simple diffusive model of transport of a non-conservative tracer from a continental source to an oceanic sink through a coastal zone, as in

$$\frac{\partial c}{\partial t} = K \frac{\partial^2 c}{\partial x^2} - \alpha c$$

show that a "half-life" of  $\gg 5$  years can probably not be distinguished from truly conservative behavior. The model may be modified to include an exponentially varying input function, as from inshore sediments. This model is applied to published data on  $\text{Ra}^{228}$  ( $t_{1/2} = 5.75$  years) as an example. Estimates of removal processes of shorter time scale are given. We conclude that basic data on coastal to oceanic elemental gradients, and the adsorptive properties of marine particulate matter, are sadly lacking.

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Supported by: *U.S. ERDA (Energy Research and Development Administration) contract AT(11-1)-3566.*

THE DETERMINATION OF IODIDE IN SEAWATER BY  
INSTRUMENTAL NEUTRON ACTIVATION ANALYSIS

George T.F. Wong and Peter G. Brewer

We have developed a simple and highly sensitive method for the determination of iodide in seawater by instrumental neutron activation analysis. Iodide is separated from most other anions by passing seawater through a strongly basic anion exchange column. It is recovered from the column by elution with a 2 M sodium nitrate solution. Iodide is concentrated from the eluate by precipitation as palladous iodide in the presence of excess palladous ions with elemental palladium as a carrier. The elemental palladium is generated by reduction of some of the excess palladous ions with sodium thiosulfate. The precipitate is separated from the supernatant liquid by filtration. Checks on the efficiency by means of added  $\text{I}^{125}$  showed recoveries of  $100 \pm 3\%$ . The filter paper containing the precipitate is pressed into the form of a pellet. This is analyzed by instrumental neutron activation analysis using a five minute irradiation at a flux of  $4 \times 10^{12} \text{ n cm}^{-2} \text{ sec}^{-1}$  and counting the  $^{128}\text{I}$  442.7 KeV photopeak.

Supported by: *National Science Foundation Grant DES 74-22292.*

ALKALINITY CHANGES GENERATED BY PHYTOPLANKTON GROWTH

Peter G. Brewer and Joel C. Goldman

Continuous cultures of three marine phytoplankton species, *Phaeodactylum tri-cornutum*, *Dunaliella tertiolecta* and *Monochrysis lutheri*, were monitored for changes in alkalinity of the culture medium resulting from  $\text{NO}_3^-$  and  $\text{NH}_4^+$  uptake. Uptake of  $\text{NO}_3^-$  caused an increase in alkalinity, whereas uptake of  $\text{NH}_4^+$  produced a decrease. These results are consistent with the type of schematic equation proposed by Redfield, Ketchum and Richards (1963) for photosynthetic assimilation of inorganic nitrogen, in which  $\text{NO}_3^-$  uptake is balanced by  $\text{OH}^-$  production and  $\text{NH}_4^+$  uptake leads to  $\text{H}^+$  generation. These reactions suggest uptake of charged nitrogen species by microbes. However, we have been unable to demonstrate the exact stoichiometry of this relationship. The role of P uptake in the alkalinity change is unclear. The data in fact show an offset, functionally equivalent to the production of some strong acid, possibly due to reactions on the walls of the vessel or resulting from active uptake of cations and/or extrusion of  $\text{H}^+$  ions by the growing cells.



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#### MANGANESE IN SEA WATER AND THE MARINE MANGANESE BALANCE

Michael L. Bender, Gary P. Klinkhammer and Derek W. Spencer

Sargasso Sea surface water samples, collected in a variety of ways, have been analyzed for dissolved manganese. The results show that, if reasonable precautions are taken, samples can be collected in 30 l PVC Niskin bottles having surgical tubing closures without detectable contamination.

Surface water samples from the Sargasso Sea, the western North Atlantic, and the Northeast Pacific all have manganese concentrations of about 0.1 ppb. Sargasso Sea and Northeast Pacific deep water samples have concentrations about a factor of four lower; concentrations in the North Atlantic western boundary current appear intermediate.

The data suggest that manganese is removed from sea water much more rapidly than the general oceanic turnover time of about 1500 years.

Downward transport of manganese in downwelling surface water and falling biogenic debris can supply only a few percent of the total amount of that element accumulating in pelagic sediments, although it can supply all the manganese accumulating in ferromanganese crusts and nodules. A Sargasso Sea and a Northwest Pacific profile show no indication of a deep water manganese maximum, suggesting that submarine volcanism and hydrothermal input is not a major source of manganese to either deep ocean water or normal pelagic sediments. Since the sedimentary manganese is supplied neither by dissolved manganese in sea water nor by hydrothermal inputs, we conclude that the "excess" manganese in pelagic sediments derives from terrigenous particles.

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## RADIOCHEMISTRY

#### A NEW, SIMPLE METHOD FOR GENTLY COLLECTING PLANKTONIC PROTOZOA

Linda B. Graham, Arthur D. Colburn and John C. Burke

An easy and gentle method for collecting planktonic protozoa is described. In this technique a one-liter polyethylene bag attached to a stainless steel, spring-hinged sampling device is operated from a standard heavy-duty fishing rod and reel. The sampler has been used successfully at depths from 1 to 300 m in ocean and in coastal waters. Acantharia and Foraminifera collected by this technique appear in excellent physical condition.

Supported by: *U.S.ERDA (Energy Research and Development Administration) contract E(11-1)-3563.*

*COMPARISON OF THE DISTRIBUTIONS IN MARINE SEDIMENTS OF THE FALLOUT DERIVED  
NUCLIDES  $^{55}\text{Fe}$  AND  $^{239,240}\text{Pu}$ : A NEW APPROACH TO THE CHEMISTRY OF  
ENVIRONMENTAL RADIONUCLIDES*

Laurence D. Labeyrie, Hugh D. Livingston and Vaughan T. Bowen  
Collaborators: S. A. Casso, A. G. Gordon, C. L. Miller, D. R. Mann, J. C. Burke,  
and B. L. Olson. Also J. Caspieri and from the ships' parties on our various cruises.

We present data showing the distribution of  $^{55}\text{Fe}$  radioactivity in marine sediment cores taken from a large range of water depths; these data are compared with the  $^{239,240}\text{Pu}$  analyses of the same or similar cores. The report is preliminary in that only a small part of the world ocean has yet been studied.

Evaluation of the results available suggests:

First, that in a good deal of their marine geochemistry, iron and plutonium move separately.

Second, that in the open Atlantic Ocean,  $^{55}\text{Fe}$  has sedimented in association with a mixed population of particles, exhibiting a mean sinking rate of about 350 m per year.

Third, part of the iron in coastal sediments is redissolved, probably by reduction associated with decaying organic matter; this process affects a higher proportion of the  $^{55}\text{Fe}$  than of the total iron. The solubilized iron should reprecipitate, after return to the overlying water and oxidation, as microparticulates. These very fine particles, dispersed by currents, may translocate  $^{55}\text{Fe}$  toward the open sea, only slowly becoming associated with larger, faster-sinking, mineral particles. It is suggested that this process may be important in the translocation of other insoluble trace elements, and even of part of the  $^{239,240}\text{Pu}$ .

Supported by: *U.S. Energy Research and Development Administration contracts E-(11-1)-3563 and E-(11-1)-2379.*

*CONTRASTS BETWEEN THE MARINE AND FRESHWATER BIOLOGICAL INTERACTIONS  
OF PLUTONIUM AND AMERICIUM*

Hugh D. Livingston and Vaughan T. Bowen

Collaborators: John C. Burke, Don R. Mann, John G. Farmer, Allan G. Gordon, Charlotte M. Lawson, Julianne M. Palmieri, John Goodrich-Mahoney, David L. Schneider and G. C. LeTendre.

From the authors' recent work data are presented showing the concentrations of Pu 239 and of Am 241 in (a) Aquatic Plants from Lake Ontario or from the North Atlantic Ocean, (b) Plankton from Lake Ontario, (c) Invertebrates (benthic) from Lake Ontario or from the North Atlantic Ocean, (d) Fish (whole or as separate organs) from Lake Ontario or from the North Atlantic Ocean. These data are discussed from several points of view, leading to the following conclusions:

1. Whether in lakes or the oceans the transuranic elements plutonium and americium are taken up by marine organisms, with concentration factors that would class them as nice, typical heavy metals. There is no evidence for strong, widespread discrimination against the transuranics by either plant or animal absorptive surfaces.

2. In both freshwater and marine situations the major reservoir of Pu and Am soon becomes the sediments, and organisms are more exposed to uptake of these nuclides the closer is their ecological involvement with the sediments.

3. Although there is little evidence that this can be an ionic strength effect, it does appear that Pu may be somewhat more available, biologically, in marine environments, and Am, conversely, in fresh water. We incline to the belief that details of these behaviors are usually controlled by local availability of organic complexers.

4. No compelling evidence exists of increase in Pu concentration at higher levels of food chains; in marine situations this appears true of Am as well, but a few data suggest that in fresh water fish there is a progressive increase, in higher trophic levels, in the ratio Am to Pu.

5. Although marine and fresh water biogeochemistries of transuranics are much more similar than we had expected, it will generally be dangerous to extrapolate from one to the other. In both systems there appears to us no question that we are observing real element biogeochemistry, not the redistribution of inert, labelled, fallout fragments.

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*INTERCOMPARISON OF  $^{137}\text{Cs}$  CONCENTRATIONS MEASURED AFTER in situ ABSORPTION, WITH THOSE DETERMINED BY BULK WATER ANALYSES OR CALCULATED FROM  $^{90}\text{Sr}$  ANALYSES*

Stuart L. Kupferman and Vaughan T. Bowen

Collaborators: Laurence J. Murphy, Newell Garfield, Hugh D. Livingston, S. M. MacKenzie, T. Lewis, R. C. Fettis and D. R. Mann.

Concentrations of  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  obtained (at Woods Hole Oceanographic Institution) by bulk water analysis were compared with  $^{137}\text{Cs}$  concentrations obtained (at University of Delaware) following absorption *in situ*. Five groups of profiles from the North Atlantic were used. Bulk water values and *in situ* values were compared by plotting radioisotope concentrations against  $\sigma$  and comparing values, obtained by linear interpolation, at the same values of  $\sigma$ . Differences obtained in this way, when compared with mean analytical uncertainties indicate that data obtained by the two methods are in excellent agreement. The systematic difference between analyses performed by the two methods appears to be close to 0.6 dpm per 100 liters.

Supported by: *National Science Foundation grants GA-28752 and DES 74-23680 (at the University of Delaware) and U.S. Energy Research and Development Administration contract E(11-1)-3563 (at Woods Hole Oceanographic Institution).*

*DISTRIBUTIONS OF TRANSURANIC NUCLIDES IN THE OCEANS:  
POSSIBILITIES FOR THEIR CYCLING*

Vaughan T. Bowen

Collaborators: J. C. Burke, S. A. Casso, O. A. Fennelly, A. G. Gordon, J. E. Gou-dreau, L. B. Graham, M. R. Hess, S. R. Johnson, L. Labeyrie, C. M. Lawson, T. Lewis, H. D. Livingston, S. MacKenzie, D. R. Mann, B. L. Olson, J. M. Palmieri, D. L. Schneider, L. D. Surprenant.

Four transuranic elements are now measurable, either locally or worldwide, in the oceans. The small amount of data available for neptunium and curium is briefly summarized. Largely from the author's own research, distributions of plutonium and of americium are shown as follows:

1. Vertical profiles of concentrations in water columns of the North and South Atlantic Oceans.
2. Vertical profiles of concentrations in water columns of the Pacific Ocean about 30°N.
3. Vertical profiles of concentration in sediment columns of the shallow North-western Atlantic Ocean, showing changes in the shape of the curves between 1964 and 1973.
4. The relation between the depth of overlying water and the sediment inventory of plutonium, in open ocean cores.
5. The relation between Pu 239 and Am 241 concentrations, and depth within a sediment core.
6. Vertical profiles of Pu 239 and Cs 137 concentration in three sediment cores from the Northeastern Pacific Ocean.

Briefly summarized, the evidence appears to show that in oceanic water columns, in the sediments, and in organisms, plutonium and americium have been more or less separated. We have still few clues what may be the processes available. Comparison of the transuranics with Fe 55, Cs 137, and other fallout nuclides shows that the transuranics have behaved in ways, and moved at rates, that are unique to themselves, confirming that they have indeed their own biogeochemistry and that we are studying it. There seems to us no possibility that these data could have been generated by movement of inert-fused fragments of nuclear debris, as is sometimes suggested.

The pathways through the water and biota into the sediments are beginning to be clarified, and we can attach rates to some of these. We believe that in much of the world ocean residence of plutonium or americium within the sediments is short, compared to the physical half-lives of the nuclides involved. This clearly indicates the existence of true cycles of these elements, in the biogeochemical sense, but we have still only a few scattered clues to the pathways involved.

This paper was presented at IAPSO Symposium, "Marine Chemical Aspects of Water and Air Pollution", Grenoble, France, Sept. 1975.

Supported by: *U.S. Energy Research and Development Administration contracts E(11-1)-3563.00, from the GEOSECS program of the International Decade of Ocean Exploration, and from contract E(11-1)-2379 with the SANDIA Laboratories.*

*RELEASE PATHWAYS FOR DEEP SEABED DISPOSAL OF RADIOACTIVE WASTES*

D. R. Anderson, W. P. Bishop, V. T. Bowen, J. P. Brannen, W. N. Caudle, R. J. Detry, T. E. Ewart, D. E. Hayes, G. R. Heath, R. R. Hessler, C. D. Hollister, K. Keil, J. A. McGowan, R. W. Rohde, W. P. Schimmel, C. L. Schuster, A. J. Silva, W. H. Smyrl, B. A. Taft, D. M. Talbert (in alphabetical order).

Collaborators: H. D. Livingston, D. R. Mann, C. M. Lawson and D. L. Schneider

The concept of disposal of high-level solidified and encapsulated radioactive wastes into the deep sea floor has recently been discussed. Such a scheme has conceptual advantages in that the areas of the mid-plate/mid-gyre regions of the oceans are relatively unproductive biologically and relatively devoid of cataclysmic events, and natural processes there are generally quite slow. Given a lack of singular events, a set of barriers against the dispersion of the radioisotopes may be defined.

The inverse of these barriers is the set of mechanisms by which the isotopes are transported from the burial site through the barriers to parts of the ocean of immediate significance to mankind. These include: corrosion of the cask; leaching of the waste material; upward transport of the isotopes with the upward moving pore water (mediated by ion-exchange processes); biological transport through bioturbation in the upper sediment layers and lowest water layer; the slow throughput currents of the deep basins; advection and diffusion through the water column; thermally driven transport through the sediments or the water column; biological transport of incorporated isotopes across the seabed or upward through the water column.

In principle, the rates of all of these processes are measurable or capable of being estimated. Such estimates are given on the basis of present knowledge of the processes in the deep basins. A methodology is discussed for the analytical treatment of the set of processes to give the amount of the isotopes reaching some part of the environment (e.g., an oceanic regime of immediate significance to man) as a function of time.

We conclude that disposal in the deep seabed is conceptually attractive because of the stability and predictability of the environment, but that it is not possible to give a firm estimate of the safety of such a scheme from our current knowledge of the mid-plate/mid-gyre regions.

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*DISTRIBUTIONS OF TRANSURANIUM NUCLIDES IN SEDIMENTS AND BIOTA OF THE NORTH ATLANTIC OCEAN*

Vaughan T. Bowen, Hugh D. Livingston, John C. Burke

Collaborators: J. C. Burke, S. A. Casso, A. G. Gordon, T. Lewis, H. D. Livingston, D. R. Mann, C. M. Lawson, B. L. Olson, J. M. Palmieri, D. L. Schneider, L. D. Surprenant.

The effects of the interaction of marine sediments with their biotic population on the penetration, redistribution, sediment association and biotic availability of delivered transuranium nuclides are discussed as a function of both sedimentation regimes and in-fauna populations. Data on the penetration and redistribution patterns of fallout transuranium nuclides in the shallow sediments

of Buzzards Bay, Massachusetts, are discussed in terms of the known parameters of sedimentation and 'in sediment' biological activity. In this (and most common) type of sedimentation regime, translocation of bioturbationally downmixed transuranium nuclides back toward (and probable loss from) the sediment surface is demonstrated. Various biological and biochemical mechanisms are advanced that may act on these nuclides within sediments. The increased availability to marine biota of sediment transuranium nuclides by these remobilization processes, is indicated by data showing accumulations of these nuclides in marine invertebrates and fish.

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*A REPORT OF THE STUDY PANEL ON ASSESSING POTENTIAL OCEAN POLLUTANTS TO THE OCEAN AFFAIRS BOARD, COMMISSION ON NATURAL RESOURCES, NAT'L. RESEARCH COUNCIL. NATIONAL ACADEMY OF SCIENCES, WASHINGTON, D. C.*

Workshop Panel

H. Volchok, Chairman  
V. Bowen  
R. Dyer  
W. Forster

J. Herring  
J. Perkowski  
T. Rice  
J. Stannard

Background Paper

J. Herring  
J. Perkowski

Collaborators: Hugh D. Livingston, Don R. Mann and John C. Burke.

On balance, our findings indicate an insufficiency of information regarding the chemical and biological behavior of the transuranics in the marine environment. Without such information meaningful quantitative assessment of either current or future impacts is not possible. We cannot dismiss the possibility that marine concentrations of one or more transuranics may approach levels of concern through naturally-acting mechanisms which we do not understand. Present evidence indicates that transuranic elements introduced to marine waters are rapidly transferred to the sediments. If this holds true, then any input from waste treatment or reprocessing will mainly affect the coastal zone near the point of introduction. These sources would, then, not be expected to contribute significantly to open ocean pollution which would be largely due to fallout from atmospheric releases. Predictions of the effects of transuranic elements on the marine environment cannot be formulated until more extensive knowledge of their modes of transport and their biogeochemical and radiobiological behavior is available. On this basis, we recommend conservative approaches to any releases of transuranic elements to the environment. This applies to planning against accidental releases as well as to any planned releases. Both should be kept to an absolute minimum.

Published in: *Transuranic Elements. Chapter 3 in Assessing Potential Ocean Pollutants. 1975.*

Supported by: *U.S. Energy Research and Development Administration (ERDA) contract E(11-1)-3563.00.*

*<sup>241</sup>Pu IN THE MARINE ENVIRONMENT BY A RADIOCHEMICAL PROCEDURE*

Hugh D. Livingston, David L. Schneider and Vaughan T. Bowen  
 Collaborators: John C. Burke and Lolita D. Surprenant

A purely radiochemical method is described for analysis of <sup>241</sup>Pu in environmental samples. Data are given showing that fallout-contaminated marine samples, of several kinds and provenances, exhibit <sup>241</sup>Pu/<sup>239/240</sup>Pu ratios slightly higher than, but not certainly distinguishable from, those reported for fallout-contaminated soils. Such ratios, however, in samples from several planned or accidental Pu releases, are clearly different, suggesting <sup>241</sup>Pu will be a useful tracer in following the spread of released Pu. The data have also clear implications for the source, and growth, of environmental <sup>241</sup>Am.

Published in: *Earth and Planetary Science Letters* 25. 1975.

Supported by: U.S. Atomic Energy Commission (AEC) contract AT(11-1)-3563.00 (now ERDA).

*A PROCEDURE FOR ANALYSIS OF AMERICIUM IN MARINE ENVIRONMENTAL SAMPLES*

Richard Bojanowski, Hugh D. Livingston, David L. Schneider and Don R. Mann  
 Collaborator: Mrs. Brenda Olson

A method is described for the measurement of americium in marine environmental samples. Some data are presented to show the method is capable of acceptable accuracy and precision. An extensive series of notes discusses the rationale for various steps in the procedure.

Published in: *Reference Methods for Marine Radioactivity Studies II*. IAEA, Vienna, 1975.

Supported by: U.S. Atomic Energy Commission (AEC) contracts AT(11-1)-3563 and AT(11-1)-3568. R. Bojanowski worked at WHOI on a UNESCO fellowship.

*MEASUREMENT OF <sup>55</sup>Fe FROM NUCLEAR FALLOUT IN MARINE SEDIMENTS AND SEAWATER*

Laurent D. Labeyrie, Hugh D. Livingston and Allan G. Gordon  
 Collaborators: C. Lynette Miller, Susan A. Casso, Charles Peters  
 and Donald F. LeBlanc

An improved windowless gas-flow proportional X-ray detector has been used to make more sensitive and convenient measurement of nuclear fallout-derived <sup>55</sup>Fe in freshwater and marine sediments. The iron extracted from a sediment is radiochemically purified and a part (about 500 mg) electroplated on an area (200 cm<sup>2</sup>) of the inside wall of a copper cylinder. This cylinder in turn becomes the cathode of the X-ray detector. A specially designed anti-coincidence multi-electrode gas-flow proportional detector surrounds the X-ray detector and reduces its background in the Mn X-ray region to 0.09 counts/min KeV. The detection sensitivity (precision ± 50%) for the measurement of <sup>55</sup>Fe in typical sediments is around 16 disintegrations/min kg of dry sediment.

Published in: *Nuclear Instruments and Methods* 128. 1975.

Supported by: U.S. Energy Research and Development Administration (ERDA) contract E(11-1)-3563.00.

*DOUBLE-TRACER STUDIES TO OPTIMIZE CONDITIONS FOR THE RADIOCHEMICAL SEPARATION OF PLUTONIUM FROM LARGE SEAWATER SAMPLES*

Hugh D. Livingston, Don R. Mann and Vaughan T. Bowen  
Collaborators: Brenda Olson Dempsey, Richard Fettis and Susan MacKenzie

The results of experiments using double-tracer techniques with  $^{236}\text{Pu}$  and  $^{242}\text{Pu}$  to optimize conditions in the radiochemical separation of plutonium from large volume seawater samples are presented. These show that the major areas of loss are the iron hydroxide precipitation step, the adsorption of plutonium on the anion exchange resin and the final electrodeposition procedure. Data are presented that show that the use of increased weight of iron 0.5 - 1 mg per sample greatly improves the recovery. The use of hydrogen peroxide to ensure oxidation of the plutonium to the 4+ state is also recommended to improve retention on the anion resin. It is well-known that the 3+ state of Pu is little adsorbed. Electrodeposition can also be improved using ammonium sulphate and longer plating times at smaller current densities.

Published in: *Reference Methods for Marine Radioactivity Studies II*. IAEA, Vienna, 1975.

Supported by: *U.S. Energy Research and Development Administration (ERDA) contract E(11-1)-3563.00.*

*AMERICIUM  $^{242m}$  IN NUCLEAR TEST DEBRIS*

Vaughan T. Bowen and Hugh D. Livingston  
Collaborators: Don R. Mann and David L. Schneider

Report is made of the finding of the long-lived metastable isomer americium  $^{242m}$  in debris from a 1962 nuclear test; the nuclide was identified by measuring its daughter curium 242. It is pointed out that this finding, probably generalizable to most nuclear explosions, and certainly to high-burn-up reactor wastes, implies both the existence of a supported (and hence long-persistent) moiety of Cm 242, and the existence of a fraction of the Pu 238 (that originating by decay of Cm 242) of quite different radiogenic history from that generally considered. Both the Cm 242 and the Pu 238 originating from Am  $^{242m}$  decay may have environmental mobility higher than the major fractions of the respective nuclides.

Published in: *Nature*, 256, 1975.

Supported by: *U.S. Atomic Energy Commission (now ERDA) contract AT(11-1)-2379.*

*CHLORINATED HYDROCARBON POLLUTANTS AND PHOTOSYNTHESIS OF MARINE PHYTOPLANKTON: A REASSESSMENT*

Nicholas S. Fisher. Received general assistance from Brenda Olson.

The chlorinated hydrocarbons DDT and PCBs (polychlorinated biphenyls), ubiquitous pollutants of the marine environment, have been observed to reduce the cell division rate of marine phytoplankton, thereby indirectly reducing the total photosynthetic carbon fixation in treated cultures. The photosynthetic capacity of



each cell was not affected. Total marine photosynthesis will likely remain undiminished by these compounds, although alterations in phytoplankton communities through selective toxicity could affect herbivore populations.

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#### TRANSURANIC ELEMENTS IN MARINE ENVIRONMENTS

Vaughan T. Bowen

Collaborators: J.C.Burke, S.A.Casso, O.A.Fennelly, A.G.Gordon, J.E.Goudreau, L.B.Graham, M.R.Hess, S.R.Johnson, L.D.Labeyrie, C.M.Lawson, H.D.Livingston, S. MacKenzie, D.R.Mann, B.L.Olson, J.M.Palmieri, D.L.Schneider and L.D.Surprenant.

Transuranic elements are present in marine environments as a result of six types of human activity: 1. worldwide fallout, 2. close-in fallout, 3. the SNAP-9A burnup, 4. pipeline disposal of reprocessing wastes, 5. neutron capture by uranium in one-pass cooling-water reactors and 6. the B-52 crash in Thule, Greenland.

Distributions and movements of these nuclides from these introductions are being studied partly because the transuranic elements themselves are geochemically interesting, partly because they appear to serve as tracers for specific oceanographic processes, and partly because of concern that man is faced with the problem of disposal of rapidly increasing amounts of transuranics as radioactive waste, and that we must be able, soon, to predict the fates and the effects of those amounts that reach the coastal waters or the deep oceans.

Plutonium and americium are widely distributed in the oceans as a result of man's activities. Both appear to be more mobile than expected, and Pu shows little behavior in these environments that had been predicted from laboratory studies. Although their associations with biological material seem to be most striking for rooted plants or Sargassum, it is too premature to dismiss the possibility of their being a real hazard to marine life. For all the abundantly produced transuranics (neptunium, plutonium, americium, and curium) many more data are needed.

Published by: *U.S. Energy Research and Development Administration, Health and Laboratory Report, HASL-291. 1075.*

#### MAGNETOTACTIC BACTERIA

Richard P. Blakemore

Highly motile marine bacteria, abundant in fresh or stored marine surface sediments collected near Woods Hole, exhibited a magnetotactic response. Initially, a geomagnetic response was observed in that cells migrated poleward when sediments containing them were disturbed. This response was directionally independent of oxygen or light. In subsequent experiments, these bacteria were alternately attracted and repelled when the polarity of an electromagnet or the position of a permanent magnet in their vicinity was reversed. Chemically-killed cells failed to migrate poleward although they still rotated in response to changes in magnet

position. Cells were harvested from mud kept in the laboratory by application of a magnetic field and were studied by optical and electron microscopy. The organisms have not been isolated in pure culture. Cells measured 1 micrometer in cross-section and were roughly spherical, with a gram-negative wall, internal membranes and numerous flagella. Electron opaque granules or crystals were arranged adjacent to the cell membrane within each cell. Typically, two chains were present, each containing 5-10 of these structures. Cell inclusions of this type have not been reported. It is tempting to speculate that they function in the magnetotactic phenomenon.

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*L-ARGININE CATABOLISM BY Treponema denticola.*

Ecole Canale-Parola and Richard P. Blakemore

*T. denticola*, an anaerobe commonly present in the human mouth, ferments various amino acids and carbohydrates. Amino acid analysis indicated that substrate amounts of arginine were utilized by *T. denticola* strain 10 growing in a complex, serum-containing medium. Cell suspensions metabolized L-arginine to citrulline, CO<sub>2</sub>, NH<sub>3</sub>, proline, and to small amounts of ornithine and of a substance suspected to be putrescine. CO<sub>2</sub>, NH<sub>3</sub>, proline, ornithine and, presumably, putrescine were produced from L-citrulline. Determinations of radioactivity in products formed from uniformly labeled L-(<sup>14</sup>C)ornithine indicated that cell suspensions converted this amino acid to proline. Furthermore, proline was excreted by cells growing in a complex arginine-containing medium. Arginine iminohydrolase, ornithine carbamoyltransferase, and carbamate kinase activities were detected in *T. denticola* cell extracts. Carbamoylphosphate dissimilation by extracts was coupled to adenosine triphosphate formation.

The data indicate that *T. denticola* derives energy by dissimilating arginine via the arginine iminohydrolase pathway. However, unlike some of the other bacteria which utilize this pathway, *T. denticola* does not accumulate ornithine as a major end product of arginine metabolism, but converts the former amino acid largely to proline.

Published in: *Abstracts of the Annual Meeting of the American Society for Microbiology*. 1975.

Supported by: *U.S. Energy Research and Development Administration (ERDA), National Institute of Health*.

*EFFECTS OF A CHLORINATED HYDROCARBON POLLUTANT  
ON THE GROWTH KINETICS OF A MARINE DIATOM*

Nicholas S. Fisher, Robert R. L. Guillard, and Charles F. Worster

*Thalassiosira pseudonana* (clone 3H, estuarine isolate), a centric marine diatom, was grown at different nitrate concentrations in the presence or absence of polychlorinated biphenyls (PCB), widespread aquatic pollutants. A hyperbola adequately described the relationship between the diatom's growth rate and the

nitrate concentration. Its growth rate was unaffected by the PCB at high nitrate concentrations but greatly reduced at low nitrate concentrations. The half-saturation constant for growth was increased from 0.21 to 3.04  $\mu\text{M}$  of N while the maximum growth rate of 3.67 divisions per day remained unchanged. Such inhibition is characteristic of competitive enzyme inhibition and suggests that the PCB may have interfered with one or more enzymes involved in nitrogen uptake or metabolism.

Supported by: *The Sarah Scaife Foundation.*

*POLLUTION TOXICITY TESTS AND THE PROBLEM OF INTERACTING VARIABLES*

Nicholas S. Fisher

Laboratory experiments investigating the toxic effects of pollutants on biological systems can be designed to yield information that is of theoretical as well as practical interest. Pollutants can be used as model stresses with which to disturb individual organisms, populations, or communities to gain a fuller understanding of the ways they respond to stress and the ecological and evolutionary implications of the responses.

The results of chronic toxicity experiments in which the test organisms are exposed to sublethal levels of pollutants under a variety of environmental conditions are more useful in determining the dangers of a pollutant in nature than are the results of the standard acute toxicity tests in which organisms are maintained under constant, ideal conditions. The chronic toxicity tests have indicated that synergistic interactions between pollutants and other factors do occur, with pollutants generally decreasing the niche breadths of sensitive species. Studying these synergistic interactions may reveal or clarify relationships between stress and the niche breadth of a species as well as aid in the assessment of the pollutant's effects in nature. These concepts are illustrated by examining those experiments which have observed synergistic interactions between various environmental conditions and the toxicity of pollutants to algae.

Supported by: *The Sarah Scaife Foundation and U.S. Energy Research and Development Administration (ERDA) contract E(11-1)-3563.00.*

*ECOSYSTEM DIFFERENCES IN VULNERABILITY TO PERTURBATION:  
AN EXPERIMENTAL APPROACH USING EXOTIC CHEMICAL STRESS*

Nicholas S. Fisher

Collaborator: Received general assistance from Brenda Olson

Phytoplankton from estuarine waters have been shown to be considerably more tolerant than open-ocean algae to physical stress but less specialized at exploiting their environment. In a series of experiments, different clones of phytoplankton isolated from the Sargasso Sea and from temperate zone estuaries were grown in culture and exposed to several toxic chemicals which they have presumably never experienced in their evolutionary histories. Intraspecific differences in sensitivity were noted, with growth of the estuarine clones always being less affected by these novel chemical stresses than growth of the oceanic clones. These results are consistent with the concept that physiologically distinct races of marine phytoplankton exist. They further suggest that phytoplankton and other organisms

inhabiting environments which select for adaptations (in the case of phytoplankton, probably involving membrane system adaptations) that permit viable nutrient exploitation at low ambient concentrations, may be (as a byproduct of these adaptations) more vulnerable to any toxic compounds (possibly any perturbations) than would organisms inhabiting physically controlled, fluctuating environments.

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# GEOLOGY and GEOPHYSICS

GG-1

DEPARTMENT OF GEOLOGY AND GEOPHYSICS

John I. Ewing, Department Chairman

## GEOLOGY

*EROSION AND SEDIMENTATION AROUND MYTILUS SEAMOUNT,  
NEW ENGLAND CONTINENTAL RISE*

David A. Johnson and Peter F. Lonsdale

The presence of Mytilus Seamount within the axis of the Western Boundary Undercurrent of the North Atlantic has modified the bottom water's flow pattern (measured by four current meters) and thermal structure (measured by a thermometer attached to a deeply towed instrument package). Attempts at bottom photography indicate that very high concentrations of suspended matter are present within a layer of isothermal ( $\theta = 1.7^{\circ}\text{C}$ ) bottom water which covers the rise locally at the foot of the northern slopes of the seamount. Erosional channels up to 50 m deep have been incised into Pleistocene and Recent continental rise sediments. The sediment-covered crest of the seamount is overlain by clear water, and exhibits bedforms and truncated sediment horizons indicative of strong scour by dominantly tidal currents.

Supported by: *Office of Naval Research Contract N00014-74-C-0262; NR 083-004.*

*THE BLACK SEA AND THE SEA OF AZOV*

David A. Ross

The Black Sea is one of the world's largest marginal seas having an area of 432,000 km<sup>2</sup> and a volume of 534,000 km<sup>3</sup>. A major part of the basin is deeper than 2,000 meters and its maximum depth is 2,206 meters. It is connected by a narrow passage, the Kerch Strait, to the shallow Sea of Azov which has an area of about 37,500 km<sup>2</sup> (excluding the Sivash or Putrid Sea) and a volume of about 470 km<sup>3</sup>. The average depth of the Sea of Azov is close to 12 meters. The sill depth between the two seas at the Kerch Strait is about 5 meters. The Black Sea is connected to the Mediterranean Sea via the shallow Bosphorus (sill depth about 50 m). The Sivash or Putrid Sea is a shallow area separated from the Sea of Azov by a 110 km long sand bar called the Arabatskaya Strelka.

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*MANNED SUBMERSIBLE OBSERVATIONS IN THE FAMOUS AREA MID-ATLANTIC RIDGE**GEOLOGISTS MAKE DIRECT OBSERVATIONS OF VOLCANIC AND  
TECTONIC PROCESSES ASSOCIATED WITH ACTIVE SPREADING CENTER*

R. D. Ballard, W. B. Bryan, J. R. Heirtzler,  
G. Keller, J. G. Moore, Tj. van Andel

Project FAMOUS (French-American Mid-Ocean Undersea Study) was conceived three years ago, its objectives being to define the tectonic and volcanic processes associated with genesis of new oceanic crust. A small area on the Mid-Atlantic Ridge centered at about 36°50'N was selected for detailed study on the basis of scientific and logistic criteria. This area has been the subject of more than 25 detailed surface ship cruises by scientists and ships from the United States, France, Canada, and England, and culminated in the first manned submersible studies of a mid-ocean ridge by the French submersible *Archimede* in 1973, and by *Archimede*, *Cyana*, and the American submersible *Alvin* during the summer of 1974. The regional setting of the

dive sight was established by narrow-beam echo sounding, dredging, side-scan sonar and deep-tow surveys, photography, aeromagnetic surveys, and shipboard magnetic and gravity surveys. The *Glomar Challenger* on leg 37 drilled four holes starting about 18 n.m. west of the dive site. The final phase of the surface ship surveys carried out by R/V *Knorr* concurrently with the submersible program consisted of dredging, coring, detailed photographic and thermal surveys, and deployment of ocean bottom seismographs. This paper presents a preliminary summary and interpretation of some of the unique observations made by the manned submersible *Alvin* during the summer of 1974. Data from the surface ship surveys, most of which is yet unpublished, has contributed significantly to the success of the project and to some of the interpretations presented here. An accompanying article describes the related French program.

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#### LATE QUATERNARY SEDIMENTATION IN THE EASTERN ANGOLA BASIN

Brian D. Bornhold

Recent sediments in the eastern Angola Basin include calcareous oozes in the north and south (Guinea Rise and Walvis Ridge) and hemipelagic lutites and terrigenous turbidites on the Congo Cone and on the Angola Rise and abyssal plain. Slumped and ponded sediments are dominant within the Angola diapir field. Illite and montmorillonite characterize the sediments in the southern part of the basin, reflecting the source in soils of Southwest Africa and northward transport in the Benguela Current system. Kaolinite dominates the clay-mineral assemblage in the north-central part of the basin; this is derived from the tropical-humid Congo Basin and transported to the deep sea through the Congo River and canyon systems.

Piston cores from the continental rise revealed major fluctuations in the surface oceanographic conditions, primary productivity, and near-bottom depositional environment during the late Quaternary. Sediments deposited during glacial intervals contain markedly lower carbonate, higher levels of organic carbon, and more abundant siliceous biogenic components, fecal pellets, and pyrite. Sedimentation rates on the rise during the past 200-300 x 10<sup>3</sup> years have remained relatively constant, averaging 3-5 cm/10<sup>3</sup> years.

Oceanographic changes from interglacial to glacial periods, based on sediment composition and geochemistry, include:

- (1) northward extension and intensification of the Benguela Current and associated high primary productivity off southern Angola;
- (2) onset of upwelling and high surface productivity off northern Angola, Congo, and Gabon; and
- (3) major influx of bottom water into the Angola and Guinea Basins.

These conditions resulted in higher benthic productivity, a shallower lysocline, and more reducing near-bottom environment, as bottom water in the Angola Basin, produced during glacial maxima, became isolated. This "climax" bottom water was eventually mixed with the overlying water by geothermal heating.

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*ANTARCTIC BOTTOM WATER TRANSPORT THROUGH THE VEMA CHANNEL*

David A. Johnson and Scott E. McDowell

New hydrographic data, abyssal temperature profiles, and current meter observations within the main axis of the Vema Channel (near 30°13'S) and in the western branch (near 29°20'S) allow estimates to be made of the northward transport of Antarctic Bottom Water through the channel. Geostrophic calculations suggest a northward transport of  $1.4 \times 10^6 \text{ m}^3/\text{sec}$  within the main branch, assuming a level of no motion corresponding to  $\sigma_\theta = 27.90$ . Mean current velocities in the western branch at 3200 m and 4200 m, together with temperature data, allowed estimation of a velocity profile for the western branch corresponding to a northward transport of  $0.8 \times 10^6 \text{ m}^3/\text{sec}$ . Net northward transport through both branches of the channel is estimated to be  $2.2 \times 10^6 \text{ m}^3/\text{sec}$ .

Supported by: *National Science Foundation Grant GA-41185.*

*BLAKE POLARITY EVENT IN TWO GIANT CORES FROM THE GREATER ANTILLES OUTER RIDGE*

Charles R. Denham

Two large-diameter (GIANT) cores from the Greater Antilles Outer Ridge have confirmed the Blake event 0.1 m.y.B.P. as a genuine paleomagnetic reversal at least in that region. The feature is clearly defined in more than 125 stably-magnetized specimens of Last Interglacial abyssal brown clay, but its precise age and duration cannot yet be estimated reliably from these or other available data. During the reversal, positions of the virtual geomagnetic pole laid about 20° from the South geographic pole, with polarity transitions traversing paths in the Eastern hemisphere. Each core also recorded a major excursion within the Blake episode. Because the most acceptable Blake event data presently span only a small geographic area, they are insufficient for distinguishing between global and local geomagnetic models for the feature.

Supported by: *Office of Naval Research Contract N00014-74-C-0262; NR 083-004.*

*THE GEOLOGY OF HISPANIOLA*

Carl O. Bowin

At present we have a very imperfect picture of ----> the evolution of an island arc, --->. Linear chains of active volcanoes presently occur in many island arcs ---> and are associated with active subduction of an oceanic lithospheric plate beneath the arc, as are deep-sea trenches. How lithospheric underthrusting begins is much in doubt. The proposed nascent island arc in the Indian Ocean (Sykes, 1970) outward from the Java Trench, suggested by a diffuse distribution of epicenters, has as yet not been supported by further studies in the area. The development of an island arc is poorly known, and the validity of interarc spreading (Karig, 1971a, 71b) is debated. What happens to an island arc when underthrusting ceases is also a matter of conjecture. Obviously, detailed geologic studies of island arcs can and will contribute to a better understanding of these problems. This paper attempts to summarize the present geologic knowledge of the island of Hispaniola toward that undertaking.

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*PETROGRAPHY, PETROLOGY AND TECTONIC IMPLICATIONS  
OF MITRE ISLAND, NORTHERN FIJI PLATEAU*

Peter A. Jezek, Wilfred B. Bryan, Stephen E. Haggerty, and H. Paul Johnson

Mitre Island is a part of a currently inactive island arc associated with a westward subduction of Pacific plate along the Vitiaz trench.

Mitre Island samples, Pliocene in age, can be classified together with Anuda samples, of unknown age, as island arc basaltic andesites with tholeiitic tendencies. The presence of morphologically unusual iron-titanium oxides and of probably xenocrystic plagioclase suggests that at least part of the minerals observed crystallized in a magma chamber underlying the island. The samples apparently represent a mixture of magma fluid, cumulate plagioclase, pyroxene, and Fe-Ti oxides which were ponded in a crater lava lake where they were reheated by subsequent eruptions. Many of them show symplectitic magnetite formed by high temperature oxidation of olivine. The morphological complexity and compositional homogeneity of the iron-titanium oxides cannot be explained at present.

Several samples contain low temperature alteration of olivines in the form of iddingsite partly or completely surrounded by unaltered olivine. These iddingsites are dry and compositionally very close to the original olivine. It is suggested that they represent an early stage in iddingsite formation.

The presence of sulfide droplets in olivine, magnetite and ilmenite suggests a formation of immiscible sulfide liquid in the magma chamber. When this separated layer was disturbed, parts of the liquid were overgrown, by minerals crystallizing at that time, and thus protected against oxidation during and after eruption.

Subduction of the Pacific Border Plateau under the northern Fiji Plateau produced counterclockwise rotation of the Vitiaz island arc. Oblique subduction was active until a steep angle was reached between the Vitiaz trench and the motion vector of the Pacific plate. Then a strike-slip fault developed in the Vitiaz trench and the subducted plate was sheared off. Recently the strike-slip zone migrated south from the Vitiaz trench across the northern Fiji Plateau and is extending from Aoba island in the New Hebrides toward the Hazel Holme bank.

Supported by: *National Science Foundation Grant GA-28967.*

*SUBMERSIBLE OBSERVATIONS AT THE SITE 332B AREA*

James R. Heirtzler and Robert D. Ballard

During much of the summer of 1974 the submersible *Alvin*, with its tender *Lulu* and escort R/V *Knorr*, conducted dive operations on the Mid-Atlantic Ridge near the Leg 37 drill area, as part of Project FAMOUS. In June 1974 plans were made for *Alvin* to dive on one of the reentry drill sites after the *Glomar Challenger* had left and while the submersible was returning to Woods Hole for the FAMOUS area. The

primary purpose of the dive would be to examine the reentry cone for damage that may have been caused during reentry, to see how deep the cone was sitting in the bottom sediments and to observe the distribution of drilled material around the cone.

Supported by: *Deep-Sea Drilling Project, Woods Hole Oceanographic Institution.*

*THE MID-ATLANTIC RIDGE AT 33°N: THE HAYES FRACTURE ZONE*

R. H. Feden, H. S. Fleming, R. K. Perry and J. D. Phillips

A geophysical study was conducted over the Mid-Atlantic Ridge between 32-39°N and 30-40°W. A particularly deep fracture was observed which offset the ridge crest 110 km in the vicinity of 33°N. A pole of relative motion between the North American and African plates was deduced from this fracture zone as being at 63.1°N, 17°W.

Published in: *Earth and Planetary Science Letters*, 26, 1975.

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*DEEP-TOW STUDIES OF THE STRUCTURE OF THE  
MID-ATLANTIC RIDGE CREST NEAR 37°N (FAMOUS)*

Kenneth C. Macdonald and Bruce P. Luyendyk

A detailed study of the structure of the Mid-Atlantic Ridge median valley and rift mountains near 37°N (FAMOUS) was conducted using a deeply towed instrument package. The median valley may have either a very narrow inner floor (1-4 km) and well-developed terraces or a wide inner floor (10-14 km) and narrow or no terraces. The terraces appear to be non-steady state features of the rift valley. The entire depth and gross morphology of the median valley may be accounted for by normal faulting, while volcanic relief contributes to the short wavelength topography (< 2 km). Most faults dip toward the valley axis an average of 50°, and the blocks are tilted back 2°-3°. Fault dip is asymmetric about the valley axis. Active crustal extension in the inner floor and inner walls has the same sense of asymmetry as the local spreading rates, reaching a maximum of 18%. Thus, asymmetric spreading appears to be accomplished by asymmetric crustal extension on a fine scale as well as by asymmetric crustal accretion. Spreading is 17° oblique to the transform faults and shows no indication of readjusting to an orthogonal system, even on a fine scale. Eighty percent of the decay or transformation of median valley relief into rift mountain topography is accomplished by normal faults which dip away from the valley axis. Most of the outward facing faulting occurs near the median valley/rift mountain boundary. Tilting of crustal blocks accounts for only 20% of the decay of median valley relief. Most long wavelength topography in the rift mountains has a faulted origin. As in the median valley, volcanic relief is short wavelength (< 2 km) and appears to be fossil, originating in the median valley inner floor. Bending of large faulted blocks toward nearby fracture zones suggests that spreading center tectonics is affected by fracture zone tectonics throughout the length of the Famous Rift. Both the crustal accretion zone and transform fault zone are narrow, only 1-2 km wide, over short periods of time. Over millions of years, however, they appear to migrate over a zone of 10-20 km wide.

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PHYSIOGRAPHY AND STRUCTURE OF THE FAMOUS RIFT VALLEY INNER FLOOR  
OBSERVED WITH A DEEPLY-TOWED INSTRUMENT PACKAGE

Bruce P. Luyendyk and Kenneth C. Macdonald

A deeply-towed instrument survey was made in the rift valley floor of the Mid-Atlantic Ridge near 37°N (FAMOUS project). Near-bottom bathymetry, side-looking sonar (SLS) and wide-angle photography are among the data brought to bear on the definition of the American-African plate boundary and the intrusion/extrusion zone between these plates. The valley floor is 1 to 4 km wide and is occupied by eight elongate shield volcanoes which occupy 40% of the axis. Where these volcanoes, called central highs, are absent, there are sometimes shallow depressions called central lows. Photographic data show three components to the near-bottom environment: massive pillow lavas, well-sorted rock fragments, and sediment. Sediment is ubiquitous in all the photos but is scarcest along the axis and over the central highs. Pillows appear freshest here also, except for a locality found at the extreme east side of the valley. The rock fragments are evidently pillow joint blocks and are associated with spallation off steep flow fronts and fracturing from faulting. More poorly sorted fragments are associated with the large throw step faults at the valley edges. Pillow elongation approaches 10:1 and can indicate flow directions both across and along contour. Numerous fissures and small throw step faults were also seen. The SLS records show that the smoothest areas are the well-sedimented regions off the central highs which are yet to be broken by faulting at the floor edges. Four types of SLS returns were recognized: faults, fissures, flow edges and/or lava ridges, and point targets. Over 700 faults were mapped. They trend parallel to valley strike (N17°E) and are generally absent within 500 m of the axis. Fault density is highest at the east inner floor edge, reaching 35/km<sup>2</sup>. Fissures are present but not as apparent due to the nature of the data. Flow edges or ridges also align near N17°E but some trend cross-strike. The point targets are 25 m high and about 50 by 50 m and represent volcanic conelets. These align in groups and often are associated with small faults. They are not detected away from the axis.

The floor is intensely fractured with fissures and small-throw vertical faults as are portions of the inner walls, showing that the region of tensional faulting is up to 5 km wide. The absence due to burial of faults near the axis suggests that the extrusion zone is up to 1 km wide. The constructive process in the floor is virtually entirely volcanic but much of this relief is obscured by the intensive shear (normal) faulting found beyond the inner walls. Many geomorphic features of the floor bear direct analogy with those in the Icelandic rift valley and the East Pacific Rise, although differences in scale are indicated.

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NEAR-BOTTOM MAGNETIC ANOMALIES, ASYMMETRIC SPREADING, OBLIQUE SPREADING, AND  
TECTONICS OF THE ACCRETING PLATE BOUNDARY ON THE MID-ATLANTIC RIDGE NEAR 37°N

Kenneth C. Macdonald

A detailed study of the magnetic anomalies of the Mid-Atlantic Ridge crest near 37°N (FAMOUS) was conducted using a deeply towed instrument package. The most recent expression of the accreting plate boundary in the FAMOUS Rift is an alternating series of linear central volcanoes and depressions which are marked by a sharp maximum in crustal magnetization only 2-3 km wide. Spreading in the FAMOUS area is highly asymmetric with rates of 13.4 mm/yr to the east and 7.0 mm/yr to

the west. At 1.7 m.y.b.p. the sense of asymmetry reverses in direction with spreading faster to the west, resulting in a gross symmetry when averaged through time. The change in spreading asymmetry occurred in less than 0.15 m.y. Spreading in the Famous area is  $17^\circ$  oblique. Even on a fine scale there is no indication of readjustment to an orthogonal plate boundary system. Spreading has been stably oblique for at least 6 m.y., even through a change in spreading direction. The presence of negative polarity crust within the Brunhes normal epoch in the inner floor has been determined, and may be due to old crust left behind or recording of a geomagnetic field event. Crustal magnetization decays to  $1/e$  its initial value in less than 0.6 m.y. The rapid decay may be facilitated by very intense crustal fracturing observed in the inner floor. The magnetized layer is approximately 700 m thick. Magnetic studies indicate that over 90% of the extrusive volcanism occurs within the rift inner floor, and is extremely rare in the rift mountains. Magnetic anomaly transition widths vary from 1 km to 8 km with time and appear to reflect a time-varying median valley structure. The valley has either a wide inner floor and narrow terraces, in which case the volcanic zone is wide and magnetic anomalies are poorly recorded (wide transition widths); or it has a narrow inner floor and wide terraces, the volcanic zone is then narrow and anomalies are clearly recorded (narrow transition widths). The median valley of any ridge segment varies between these two structures with time. At present the Famous Rift has a narrow inner floor and volcanic zone (1-3 km) while the south Famous Rift is at the opposite end of the cycle with a wide inner floor and volcanic zone (9-11 km).

Supported by: *National Science Foundation Grant GA-36818*

*COMPOSITIONAL VARIATIONS OF YOUNG BASALTS  
IN THE MID-ATLANTIC RIDGE RIFT VALLEY NEAR  $36^\circ 49'N$*

Wilfred B. Bryan and James G. Moore

Fifty well-located samples of fresh basalt were collected from the submersible *Alvin* from the median valley of the Mid-Atlantic Ridge during the French American Mid-Ocean Undersea Study (FAMOUS) in the summer of 1974. The samples show regular compositional variations from the center of the rift valley (central lavas) out to the rift valley walls (flank lavas). The central lavas show higher ratios of olivine relative to clinopyroxene and plagioclase phenocrysts and contain chrome spinel. Glasses of the flank lavas are enriched in  $SiO_2$ ,  $TiO_2$ ,  $K_2O$ ,  $H_2O$ , and  $FeO/MgO$  relative to central lavas.

Studies of the thickness of palagonite and manganese crusts indicate that the flank lavas are considerably younger than the inferred spreading age of the crust on which they occur. Flank lavas are generally older than central lavas, but notable exceptions occur.

The composition of the flank lava glass can be derived by the removal of approximately 29 weight percent of analyzed phenocrysts (in the ratio 5.7 plagioclase, 2.5 olivine, 1.8 clinopyroxene) from the central lava glass. In addition, other processes (probably involving volatile transfer) must enrich the flank lavas in  $K_2O$ ,  $TiO_2$ , and  $H_2O$ .

A model is proposed whereby this crystal fractionation occurs in a shallow, narrow (4 km wide) magma chamber underlying the median valley. The chamber is compositionally zoned and central lavas are fed from dikes tapping its hotter axial

zone, whereas flank lavas are fed from the cooler, differentiated melt on the margins. The nature of the chemical variations in the lavas permits an estimate of the composition and thickness of the cumulates forming at the base of the chamber.

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*PROJECT FAMOUS: MORPHOLOGY AND TECTONICS OF THE INNER RIFT VALLEY  
AT 36°50'N ON THE MID-ATLANTIC RIDGE*

Robert D. Ballard and Tjeerd H. van Andel

A segment of the inner rift valley of the Mid-Atlantic Ridge was investigated in detail from the American submersible *Alvin*. Using a precision navigation and data logging system, fifteen traverses were made across the floor and up the first major fault scarps in the valley walls. The observations made are superimposed over a detailed bathymetric map of the region. The asymmetry of the inner floor is described and found to be the primary result of volcanic activity. Although tectonic activity is widespread, it acts more as a modifier of the topography. An analysis of these tectonic features revealed the rift is evolving within a single stress field which has its least principal strain axis aligned with the valley axis of N 20° E. The tectonic elements in the inner floor are primarily tensional in origin with vertical fracture planes while the fault scarps of the flanking walls are closer to 60° and reflect a component of shear. The submersible information base was broadened using information collected in the area with more conventional techniques. Through an analysis of this information, primarily the topography, it was possible to extrapolate the detailed submersible observations to intervening areas to produce a comprehensive geological interpretation of the study area. From this analysis an evolutionary model was developed which suggests that the inner rift is a product of axial volcanic activity. Shortly after formation, the original volcanic edifice is modified by vertical collapse, which leads to a reduction of the bottom relief. This process is reversed in the outer portions of the valley as uplift begins. Tensional extension changes into vertical shear as the volcanic blocks are incorporated into the walls and elevated. During the various stages of uplift, compensation takes place on the terraces which results in the preservation of the original volcanoes as recognizable units. This model, which spans 180,000 years of inferred time, is examined in detail in an attempt to identify its weaknesses as well as to delineate the specific factual constraints upon which it is built. Alternate interpretations are proposed and tested in a similar fashion; the result is the identification of key problems which need to be solved.

Supported by: *National Science Foundation Grants GA-35976, GA-41694 and GX-36024.*

*THE FLOOR OF THE MID-ATLANTIC RIFT*

James R. Heirtzler and Wilfred B. Bryan

Last summer United States and French submersibles explored a rugged area at some 8,400 feet where lava wells up and the ocean floor moves outward, bearing with it the continents to the east and the west.

Published in: *The Scientific American*. 1975.

*THE SOUTHERN OCEAN FLOOR*

James R. Heirtzler

Because of its remoteness from major oceanographic centers, and because of the continuous presence of ice and adverse weather conditions, the Southern Ocean has been relatively unexplored. Yet the sea floor is known to have characteristics not found in any other ocean area.

Little information about the sea floor was obtained by early explorers of the high southern latitudes. The first significant data were acquired by researchers aboard the ships that, in more recent times, supplied the antarctic bases of various countries. Some of the better-known regions are the area immediately south of South America, the Scotia Sea, and around the Antarctic Peninsula; somewhat less known, the areas south of Australia and south of Africa; relatively little known, the high latitudes of the southern Indian and Atlantic oceans. From 1962 through 1972, the research vessel *Eltanin* was operated by the National Science Foundation across the high latitudes of the Pacific between South America and Australia, and between Australia and Antarctica. In early 1975, this same ship, renamed *Islas Orcadas* and operated jointly by National Science Foundation and the Argentine Navy's Hydrographic Office, began exploring the high latitudes of the Atlantic. *Eltanin* has done more than any other ship in providing information about the antarctic sea floor.

Published in: *Oceanus*, 1975.

*HYDROGRAPHIC AND ABYSSAL TEMPERATURE DATA FROM THE  
VEMA CHANNEL AND RIO GRANDE RISE, Chain 115, Leg 6.*

David A. Johnson, Scott E. McDowell and Richard P. Von Herzen

Seven hydrographic stations and eight abyssal temperature profiles (from a thermistor mounted on a heat flow recorder) were obtained on *Chain* 115, Leg 6 in the southwestern Atlantic during April-May of 1974. Data were obtained within the main axis of the Vema Channel (near 30°13'S); on the east flank of the channel; within the western branch of the channel (near 29°20'S); and on the north flank of the Rio Grande Rise (near 30°00'S, 35°30'W). Temperature data confirm that a substantial northward transport of Antarctic Bottom Water is occurring through the western branch of the Vema Channel. Within the main branch of the channel, the coldest water ( $\theta < -0.18^{\circ}\text{C}$ ) is present along the eastern side at depths greater than 4300 meters. Northward transport of AABW within the main channel at 30°13'S is estimated to be  $1.4 \times 10^6 \text{ m}^3/\text{sec}$ .

Technical Report Prepared for: *National Science Foundation Grant GA-41185.*

*DESCRIPTIONS OF WOODS HOLE OCEANOGRAPHIC INSTITUTION SEDIMENT CORES*

Prepared by the Staff of the Sea Floor Samples Laboratory  
Edited by D. A. Johnson and A. H. Driscoll

This report presents visual core descriptions and smear slide analyses for all cores in the Woods Hole Oceanographic Institution geological samples collection which were obtained prior to November 1973. Approximately 1000 coring stations from

the Atlantic, Indian and Pacific oceans and adjacent seas are represented. Charts of ships' track and computer listings of all cores are also included.

Technical Report prepared for: *Office of Naval Research Contract N00014-74-C-0262; NR 083-004 and National Science Foundation Grant DES 73-06463 (formerly GA-36698).*

*ARPA ROCK DRILL REPORT*

Raymond E. Davis, David L. Williams and Richard P. Von Herzen

This report outlines the development and capabilities of the Woods Hole Oceanographic Institution's Rock Core Drill. The Rock Drill is shown to provide a relatively inexpensive means of recovering oriented bottom rock samples from the oceanic crust for magnetic and petrochemical studies. It is completely self-contained and capable of recovering 1 m long, 3/4-inch diameter, rock cores from depths to 4000 m. Most efficient deployment is from a surface vessel, but with sufficient modification it is capable of being safely transported by a DSRV.

Technical Report prepared for: *Office of Naval Research Contract N00014-75-C-0681; NR 294-017.*

*WOODS HOLE OCEANOGRAPHIC INSTITUTION'S GEOLOGICAL SAMPLES DATA FILE  
VOLUME I, 1957 TO 1973*

Alan H. Driscoll and Susan M. Rush

The sample information contained in Volume I of the W.H.O.I. Geological Samples Data File represents the first phase in the digitization of the Woods Hole geological samples collection, and includes all samples collected between 1957 and 1973. Additional volumes will be produced at regular intervals as the curation and description of subsequent samples are completed.

This volume is designed as a quick reference to the samples within the collection and has been compiled using two of the listing formats available with the MUD-DIE Program. These two listings are presented in Sections I and II of this volume. Section I contains an abbreviated listing of the samples in order of their occurrence within specific Marsden squares. An explanation of the coded terms used in the abbreviated listings is presented below.

Section II of the volume contains a full listing of the samples, arranged by ship and cruise. Appropriate comments relating to specific samples have been included.

Within Section II, individual piston cores are represented by two entries. The first entry describes the piston core, and the second entry describes the pilot gravity core. In cases where there is only one listing for a piston core, one may infer that either the piston or pilot sample was not recovered.

Technical Report prepared for: *Office of Naval Research Contract N00014-74-C-0262; NR 083-004 and National Science Foundation Grant DES 73-06463.*



## G E O P H Y S I C S

*THE CARIBBEAN: GRAVITY FIELD AND PLATE TECTONICS*

Carl O. Bowin

The application of the theory of plate tectonics is examined for a specific portion of the earth's surface: the Caribbean region. Gravity anomalies, topography, volcanoes, seismicity, and the terrestrial flow of heat are inferred to be indicators of present tectonic activity. Maps illustrating these parameters are presented. Their examination and comparison 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.

Free-air gravity anomalies in the Caribbean region are among the largest in the world, ranging from -355 mgal north of Puerto Rico over the Puerto Rico Trench to over +200 mgals on the adjacent Greater Antillean Islands. Although large positive and negative free-air anomalies are associated with portions of the margins of the Caribbean lithospheric plate, the interior regions of the Caribbean and Atlantic plates generally have anomalies within  $\pm 50$  mgal of zero, and hence are close to being in isostatic equilibrium. The Cayman Trough also is in near isostatic equilibrium, which is compatible with its origin by sea floor spreading. 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, and 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 is made within the concepts of plate tectonics. 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).

Supported by: *Office of Naval Research Contract N00014-74-C-0262; NR 083-004.*

*GEOHERMAL MEASUREMENTS IN DEEP SEA DRILL HOLES*

A. J. Brickson, R. P. Von Herzen, J. G. Sclater,  
R. W. Girdler, B. V. Marshall, and R. Hyndman

A method of measuring the *in situ* sediment temperatures in deep bore holes drilled to depths of several hundred meters or more beneath the seafloor has been developed. The technique, as presently used aboard the Deep Sea Drilling Project drilling vessel *Glomar Challenger*, involves the emplacement of a temperature sensor, located below a self-contained digital temperature recorder package, a short distance into the undrilled, thermally undisturbed sediment at the bottom of the drill hole. By measuring the *in situ* temperature at various depths in a single drill hole it is possible to calculate the thermal gradient for various intervals in the hole. This information, in conjunction with thermal conductivity data measured aboard ship on the sediment cores recovered from the drill hole, permits computation of the heat flow through the oceanic crust.

Heat-flow values measured in deep drill holes in the Indian and Pacific Oceans and in the Bering and Red Seas are in generally good agreement with the regional geothermal flux as determined by conventional near-surface heat-flow measurements, suggesting that the thousands of existent shallow heat-flow values are representative of the earth's heat flux. Where multiple down-hole temperature measurements made at one site permit calculation of interval heat-flow values, there is no consistent indication of a significant vertical increase or decrease in heat flux, such as might be caused by long-term changes in bottom-water temperature or the upward migration of interstitial fluids. We note, however, that a more detailed set of temperature measurements in a single hole is required to verify this conclusion. Down-hole heat-flow values made within a specific physiographic region, such as the Red Sea or on the Ninetyeast Ridge, appear to be less variable than, but equal to, the heat-flow values calculated using thermal gradient measurements made at shallower depths beneath the seafloor. This observation is in accordance with theoretical considerations which indicate that temperature measurements in deep drill holes are less susceptible than conventional heat-flow measurements to the disturbing thermal effects of small-scale surface topography, short-term variations in bottom water temperatures, and local sedimentary processes (slumping, erosion).

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*OBLIQUE SPREADING NEAR THE OCEANOGRAPHER FRACTURE*

Peter Bird and Joseph D. Phillips

A detailed aeromagnetic survey centered on the Mid-Atlantic Ridge was processed using a new algorithm to reduce navigational errors. Small areas within the survey were selected for multiple-directional stacking to reduce noise and determine best-fitting azimuths. This analysis allowed identification of seafloor spreading anomalies out to number 9. Anomaly azimuths indicate two periods of

oblique spreading with a left-lateral sense: from 25 to 14 m.y. ago, and from 9 m.y. up to the present. Oblique spreading may have resulted from locking of transform faults each time the African plate began to spread in a more northerly direction away from the American plate.

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#### MASCONS: A TWO BODY SOLUTION

Carl O. Bowin, Bruce Simon, and W. R. Wollenhaupt

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 ( $+0.5 \text{ gm/cm}^3$ ) 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 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 about a 2 km thickness of fill and a 12 km rise of a lunar Moho beneath Mare Serenitatis to account for 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 agreement with anomalies observed at several heights above Mare Serenitatis. The thickness of fill would be greater than 2 km if the basin floor subsided under the load of early fill material.

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#### RADIOMETRIC AGES FROM RYUKYU ARC REGION AND AN ARGON 40/39 AGE FROM BIOTITE DACITE ON OKINAWA

Carl O. Bowin and Peter H. Reynolds

A biotite dacite that intrudes metamorphic rocks on Okinawa in the Ryukyu Island Arc has been dated as 12 m.y. by the Argon 40/39 method. The details of this age measurement and a compilation of radiometric ages for the Ryukyu Island Arc and adjacent regions are presented. These data suggest that from 65 m.y. to 12 m.y. ago the magmatic axis of the Ryukyu Arc was confined to a very narrow zone along the arc. In Kyushu and Shikoku, the southern Japanese islands, intrusive and volcanic igneous rocks dated as 21 to 12 m.u. occur over a much wider zone than in the Ryukyu Arc. The apparent difference in width of the magmatic zones may be due to different absolute motions of the overthrust plates of those two regions of subduction. The dissimilarity of available radiometric ages for the Ryukyu Arc and for Taiwan suggest different histories for the development of these two features. The occurrence of active volcanoes in association with the Okinawa Trough, northwest of the Ryukyu Island Arc, may indicate that the trough itself developed in the last 12 m.y.

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*VOLCANIC AND TECTONIC EVOLUTION OF CRATER GOELENIUS, WESTERN MARE FECUNDITATIS*

Wilfred B. Bryan, Peter A. Jezek, and Mary-Linda Adams

Crater Goclenius was probably formed by impact at about the beginning of the period of volcanic activity that flooded Mare Fecunditatis. The shape of the crater was influenced by pre-existing fractures which conform to the lunar grid system, and was further enlarged and shaped by tectonic subsidence preceding and accompanying volcanic activity within the crater. Evidence for this volcanism includes a dark, mare-type fill on the crater floor; dark halo craters; and rilles, pits, and craters which show evidence of structural control. This volcanism probably coincided with the period of flooding of Mare Fecunditatis. Subsidence of the basalt-filled mare basin caused tensional stresses on the margin which produced graben subsidence along the fracture set tangent to the margin of the basin.

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*NEGATIVE GRAVITY ANOMALIES ON THE MOON*

Carl O. Bowin

Negative gravity anomalies on the moon can be categorized by whether they show a correspondence to lunar topography or appear to be unrelated to surface topography. Clear examples of the former are the negative anomalies from Doppler residual data that occur over craters such as Copernicus, Hipparchus, Ptolemaeus, Theophilus, and Langrenus. These anomalies appear to be due to mass deficiencies caused by the cratering process, in large part probably by ejection of material from the crater. Some anomalies on the far side determined from an analysis of orbital rates (Ferrari, 1975) may have a correspondence with topography, but others do not. Irregularities in the thickness of the lunar crust not related to compensation for present surface topography is inferred to be a likely source for the broad large gravity anomalies unrelated to surface topography. Localized large negative anomalies adjacent to mascons, such as those between Mare Serenitatis and Mare Imbrium or Mare Crisium, may be the result of localized depression of lunar crust adjacent to mare basins during the early stages of mare filling. Structures on the moon having a half-wavelength of 800 km or less, and large negative or positive gravity anomalies are not in isostatic equilibrium. Many of these features have mass loadings of about 1000 kg/cm<sup>2</sup> which can be statically sustained on the moon, even though such isostatic mass anomalies can not be so maintained on the earth.

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*STRUCTURE OF THE NORTHERN BRAZILIAN CONTINENTAL MARGIN*

R. E. Houtz, W. J. Ludwig, John D. Milliman and John A. Grow

Results from two-ship seismic refraction profiles and several supplementary sonobuoys show that typical oceanic crust underlies both the landward and seaward sides of the North Brazilian Ridge. The Ceara Rise also is an oceanic feature, probably uplifted by local tectonic activity. On the upper Amazon Cone, sediments are more than 11 km thick, but they thin both landward and seaward. Owing to the great sedimentary thickness, oceanic basement could not be identified, but is assumed to extend under the Cone.

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*MAGNETIC ANOMALIES IN THE WEST PHILIPPINE BASIN*

Keith E. Louden

We present a comprehensive collection of magnetic anomalies in the West Philippine Basin together with several bathymetric profiles and nannofossil age dates for JOIDES sites 290 and 291. From this data we locate symmetric magnetic anomalies that have strikes roughly parallel to the Central Basin Fault. They can be identified as numbers 17-21 if the basin originated south of the equator and opened at a rate of 41-44 mm/yr. This adds justification but not total proof for the theory that the Central Basin Fault may be an extinct spreading center which slowed and then ceased spreading 40 m.y. ago. It is still possible that island arc spreading created these anomalies, but if so, the origin and evolution of such an arc cannot be simply connected to the later development of the Parece Vela and Skikoku Basins to the east. Other results show that the elevation of this region is one kilometer lower than would be observed for similar aged crust in the North Pacific. If the JOIDES dates and our anomaly interpretations are correct, then the lack of a correspondingly large negative gravity anomaly suggests major differences between this extinct ridge and those known to be currently spreading.

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*THE BOUVET TRIPLE JUNCTION*J. G. Sclater, C. O. Bowin, R. Hey, H. Hoskins,  
J. Peirce, J. D. Phillips, and C. Tapscott

The boundaries of three plates, South America, Africa and Antarctica meet in a triple junction 200 km west of Bouvet Island. In the vicinity of the triple junction the most striking features of the Antarctica/South America and Africa/Antarctica plate boundaries are the Conrad and Bouvet fracture zones which trend N85°E and N45°E. We show by matching synthetic and observed magnetic anomaly profiles that the Antarctica/South America, Africa/Antarctica and Africa/South America plate boundaries are moving apart at half rates of  $0.90 \pm .1$ ,  $0.83 \pm .1$  and  $1.60 \pm .1$  cm/yr respectively. The rates and directions of motions for the Antarctica/South America and Africa/Antarctica plate boundaries are significantly different from those predicted by analysis of plate motions assuming global closure. The three plate boundaries meet within 10 km of 54°50'S, 00°40'W in a ridge-fault-fault

(RFF) configuration. Within experimental error the relative velocity triangle closes. The triangle is isosceles and the junction is stable. We speculate from the geometry of the boundaries that during the past 20 million years the triple junction migrated along the Mid-Atlantic Ridge by a series of jumps whenever the fracture zones on the Africa/Antarctica and Antarctica/South America plate boundaries became too long.

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*HEAT FLOW NEAR THE SOUTH ATLANTIC TRIPLE JUNCTION, 55°S, 0°E*

Tien-Chang Lee and Richard P. Von Herzen

Fifteen heat-flow values, representing the southernmost measurements made in the Atlantic, show a pattern of heat flow with tectonic features around the ridge-fracture-fracture triple junction which are explained by effects of hydrothermal circulation. High values ( $>4 \mu\text{cal}/\text{cm}^2\text{sec}$ ) on ridges which flank the axial valleys may either reflect a topographically controlled ascending limb of a hydrothermal circulation system, or result from conductive cooling of crust subsequent to the sealing of cracks generated at the spreading center. Intermediate to low values (0.4 to 1.8) in the depressions of fracture zones and axial valleys are consistent with a model of thermal cracking and subsequent hydrothermal circulation in the newly formed rocks. Low values ( $<1.3$ ) over the ridge flanks may also be a consequence of secondary circulation in cracks reopened during dehydration of rocks previously hydrated near the spreading centers. If such secondary circulation is widespread, it would imply at least two, and perhaps more, minima in profiles of oceanic heat-flow vs. age.

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*SEISMIC FILTER DESIGN USING SCATTERING FUNCTION THEORY  
AND SOURCE MONITOR SIGNALS*

Arthur B. Baggeroer and Hartley Hoskins

A detailed study of the utility of using a source monitor to improve the quality of seismic reflection profiling recordings is presented. This involves three aspects i) the development of the scattering function theory used in radar and sonar for modeling the reverberation, ii) an underway measurement of the signature using a source monitor, and iii) the application of the theory and data to seismic reflection signals. Various filters for seismic data are developed and related theoretically. Comparisons are made to convolutional filters and predictive deconvolution filters. These results indicate that for single channel reception, the availability of the source signature does not significantly improve the quality of the records.

Technical Report prepared for: *International Decade of Ocean Exploration.*

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*THE CONTINENTAL MARGIN OFF WESTERN AFRICA: SENEGAL TO PORTUGAL*

Elazar Uchupi, Kenneth O. Emery, Carl O. Bowin, and Joseph D. Phillips

About 22,000 km of continuous seismic reflection, magnetic, and gravity profiles, 118 radiosonobuoy recordings, 98,000 km of geophysical profiles from previous investigations, 15 deep-sea drilling logs, and numerous dredge samples served to reconstruct the history of the continental margin and adjacent deep-ocean floor between Senegal and Portugal. Initial structures of the margin south of Morocco formed by divergence when Africa and North America separated 180 m.y. ago. The margin off western Portugal had a similar origin when the Iberian peninsula and North America separated about 80 m.y. ago. Between these two divergent segments the area of the Strait of Gibraltar formed by a combination of translation from 180 to 72 m.y. ago and plate convergence from 63 m.y. ago to the present, with convergence becoming more intense during the past 10 m.y.

Earliest sediments atop basement include an evaporite of latest Triassic to earliest Jurassic age. When the apron deposited by upbuilding and outbuilding became thick enough, mobility of the evaporites deformed the overlying sediments especially north of the Canary Islands. Except off Morocco and the Strait of Gibraltar and possibly off southern Senegal the sediment blanket is dominantly calcareous, reflecting the general lack of fluvial influx. Included is a Middle-Late Jurassic algal reef that constitutes the lower continental slope off Morocco.

During Aptian-Cenomanian time the deep ocean off much of northwestern Africa had only sluggish bottom circulation, recorded by organic-rich sediments. A major hiatus in deep-ocean sediments and in three prominent sedimentary ridges (off Madeira, near Agadir Canyon, and north of Conception Bank) probably was caused by intensified circulation. Tertiary tectonism modified the divergent margin south of Morocco by folding of shelf strata off the western High Atlas, emplacement of the Canary Island Ridge, folding of slope strata off Spanish Sahara, and uplift of the Cape Verde Plateau. These orogenies also may have uplifted oceanic basement beneath the upper rise and formed the volcanic seamounts along this ridge.

Maximum modification by Tertiary tectonism occurred on the margin of translation-convergence near the Strait of Gibraltar. Here, the convergence phase caused uplift of Gorringe Bank. Plate convergence also tectonized sediments atop oceanic basement, aided by the mobility of Triassic-Jurassic evaporites. More recently, probably as a consequence of uplift of the Iberian peninsula during the Pliocene, well-stratified Miocene and younger deposits atop the tectonized lower unit slid oceanward away from the peninsula, with the mega-slide coming to rest against the Moroccan continental slope. Associated folding also involved the lower tectonized sequence.

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## GEOTECHNICAL PROPERTIES OF DEEP SEA SEDIMENTS: BERMUDA RISE

Armand J. Silva, Charles D. Hollister, Edward P. Laine, Bruce E. Beverly

The Giant Piston Corer has been used to obtain good quality sediment samples from several sedimentological/acoustic regimes in the northwestern Atlantic. A total of 185 m of sediment were recovered in nine cores with lengths ranging from 6.5 m to 30.5 m. Sediment types include calcareous ooze, pelagic brown clay, organic rich gray-green silty clay and graded sand. Data are presented from three of these cores, taken from three different acoustic provinces.

Seismic profiles and 3.5 kHz records from our study area on the eastern Bermuda Rise (4-5 km water depth) reveal marked differences in acoustic characteristics which are consistent with physical property variations at three of the core sites. This area contains three major features: 1) a broad, gently rolling *plateau* covered with about 300 m of sediment containing numerous conformable reflectors; 2) a *slope* region with maximum slope angle of 0.275 rad ( $16^\circ$ ) which is underlain by acoustically transparent sediments; and 3) a region at the toe of the slope consisting of sediment *hummocks* with irregular hyperbolae and occasional conformable reflectors.

The illitic sediments of the *plateau region* are a mixture of glacial and pelagic material with high rates of accumulation (20 to over 200 cm/1000 yr). The water content profile reveals large vertical variability and several zones of distinct contrasts. Shear strengths are low (average of 0.040 kg/cm<sup>2</sup>) within the upper 15 m where there is no significant increase in strength. Except for the upper 2 or 3 m which is overconsolidated, test results indicate a significant amount of underconsolidation for most of the 29 m core length. Three correlations have been made between acoustic reflectors and physical properties of the plateau core. All three of these reflectors occur at zones of high water content in the core.

The pelagic sediments of the *slope region* contain significant montmorillonite and rates of accumulation are about 1 to 3 mm/1000 yr. There are few fluctuations in water content within the cored depth of 14 m, the shear strength shows a steady increase with depth and the sediment is essentially normally consolidated. Slope stability analyses, assuming the sediment properties of the plateau region indicate that slumping due to gravity alone would occur after the accumulation of only a few meters of sediment on this slope. The acoustically transparent seismic record correlates with the lack of significant fluctuations in geotechnical properties.

The lithological and water content variability of the *hummocks* at the base of the slope is similar to that of the plateau region. The sediment column appears to be normally consolidated and the shear strengths are considerably higher than on the plateau. It is concluded that the hummocks are slumped materials which have been transported downslope intermittently.

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AEROMAGNETIC STUDY OF THE MID-ATLANTIC RIDGE  
NEAR THE OCEANOGRAPHER FRACTURE ZONE

J. D. Phillips, H. S. Fleming, R. H. Feden, W. E. King, R. K. Perry

An aeromagnetic study was conducted over the Oceanographer Fracture Zone on the Mid-Atlantic Ridge between  $33^{\circ}$  to  $37^{\circ}\text{N}$  and  $31^{\circ}$  to  $39^{\circ}\text{W}$ . A sea-floor-spreading interpretation of the magnetic anomalies reveals that the ridge crest is formed of short, en echelon segments 40 to 60 km long. These segments are offset by transform fractures. An average spreading rate of about 1.1 cm/yr active over the last 10 m.y. can be fitted to the ridge crest anomalies 2' through 6. However, positive identification of the outer flank anomalies is not possible. The ridge crest anomalies younger than 7 m.y. old (anomaly 4) show a general trend of  $\text{N}30^{\circ}\text{E}$ , but anomalies between 9.3 and 17.5 m.y. old (anomaly 5 to 5') have trends of about  $\text{N}8^{\circ}\text{E}$ . The oldest flank anomalies (anomaly 6) trend about  $\text{N}35^{\circ}\text{E}$ . Application of the anomaly trend superposition technique to account for the offset anomaly and fracture-zone pattern has allowed a new calculation of rotation pole parameters for the North American-African plate systems. For anomaly 2' (2.7 m.y. ago), the finite rotation pole is located south of Iceland at  $58.8^{\circ}\text{N}$ ,  $17.4^{\circ}\text{W}$ , with an angular rotation of  $1.26^{\circ}$ . For anomaly 5 and the older flank anomalies 5' and 6, the finite rotation poles are located near Svalbard at  $78.6^{\circ}\text{N}$ ,  $34.5^{\circ}\text{E}$ ;  $80^{\circ}\text{N}$ ,  $29.9^{\circ}\text{E}$ ; and  $80^{\circ}\text{N}$ ,  $46.1^{\circ}\text{E}$ , with angular rotations of 2.67, 3.84, and 4.64 degrees, respectively. The major change in the pole location between anomalies 2' and 5 about 7 m.y. ago appears to have been accompanied by the creation of a new transform fracture pattern with old fractures terminating and new ones being formed. Comparison of the two general pole locations deduced here with poles determined by others for the earlier opening history of the North American-African plate system shows that all finite poles lie in either of these locations. This suggests that a bi-stable dynamic equilibrium condition has prevailed throughout the opening history, with the rotation poles being located south of Iceland during the earliest period (200 to 80 m.y. ago) and the latest period ( $\sim 7$  m.y. ago to the present) of opening. During the intervening period, the poles were located near Svalbard.

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A GEOPHYSICAL STUDY OF THE RED SEA AXIAL TROUGH BETWEEN  $20.5^{\circ}$  and  $22^{\circ}\text{N}$

Roger C. Searle and David A. Ross

New bathymetric, seismic reflexion, gravity and magnetic data have been obtained in a detailed survey of part of the axial trough in the central Red Sea. These data show that the trough is not continuous, but is broken into two sections separated by a shallow region, called the 'inter-trough zone'. This zone has a thick sediment cover and is devoid of magnetic anomalies. It may represent a fracture zone into which salt and other sediments have flowed, or it may be a section of spreading axis which has remained covered with sediments for an unknown reason.

The transverse magnetic anomalies, previously recognized by Allan, Phillips and others, have been fully mapped, and a further transverse lineation has been discovered. Using three-dimensional computations, a model has been developed which

can account for these lineations as the magnetic end-effects of a series of short spreading axes offset by closely-spaced transform faults. The development of such a configuration is discussed and can be seen as a natural consequence of the plate geometry in this region.

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GEOPHYSICAL STUDY OF ANTILLES OUTER RIDGE, PUERTO RICO TRENCH,  
AND NORTHEAST MARGIN OF CARIBBEAN SEA: REPLY

R. L. Chase, E. T. Bunce, and J. D. Phillips

Monroe's first comment highlights a difference that exists between the body of our paper (Bunce *et al.* 1974) and the abstract. We thank him for bringing this to our attention and giving us the opportunity for clarification.

Specifically, in the abstract we make the statement that "the age and distribution of acoustically transparent sediments relative to layered valleys of turbidite material on the ridge *indicate* that gradual uplift and compression have been active in the region since Eocene time" (*italics added*). However, in the body of the paper (p.114) it is pointed out that the layering of the sedimentary material in the valleys extends all the way up to the present sea floor (evidence is from cores and echo-soundings) and that therefore the process by which the valley fill was deposited is still active today. The process preferred by us in the paper for creation of the valley fill is deposition from turbidity currents, which themselves result from local slumping from hills of sediment (part of the transparent layer) built up by a bottom current, probably the western boundary undercurrent. In this scenario, the sediment derived ultimately from the northwest is deposited locally as underwater "dunes" or sand ripples, then slumps and flows east and north toward the Nares abyssal plain. There is nothing here which *indicates* uplift and compression since the Eocene, although such phenomena are not *precluded*.

Origin of the layered valleys as lobes of the Nares which received their sediment from the Nares and subsequently were uplifted, which would *necessitate* uplift, is mentioned and then discounted in Bunce *et al.* (1974) because of the persistence of layering right up to the sea floor. Here we agree with Monroe.

Another scenario, not considered in the paper, would have the valleys originate as pathways for turbidity currents from the Silver abyssal plain to the Nares abyssal plain. The Silver abyssal plain now lies below 5,500 m and the Nares below 5,800 m, whereas at least some of the valleys (Fig.11 of Bunce *et al.*) lie at depths of less than 5,450 m. Thus, in this scenario, uplift of the area of the valleys by 50-100 m relative to the Silver abyssal plain must have occurred. Further investigation of the area between the Silver abyssal plain and the area of the previous detailed survey would be necessary for verification.

Monroe contends that no evidence exists favoring a plate boundary coincident with the south slope of the Puerto Rico Trench. The principal evidence for such a placement of the boundary is the distribution of seismic epicenters (see, for example, Maley *et al.*, 1974, Fig.2). The nature of displacement along the boundary is indicated by the slip vectors of earthquakes, which indicate left-lateral east-west movement (Molnar and Sykes, 1969). Though the faults on the north slope may well be due to normal faulting, like those oceanward of the axis of the Aleutian Trench (Stauder,

1968), the steep slopes on the south slope could well result from movement on high-angle reverse faults with left-lateral as well as vertical components.

The similarity of lithology and age of the basement rocks of Puerto Rico and the north slope of the Puerto Rico Trench merely indicates that in both places one has exposures of Mesozoic oceanic crust, which in one place (Puerto Rico) subsequently has been incorporated in the basement of an island arc, with appropriate plutonic intrusion, younger volcanism, and metamorphism.

Reprinted in the American Association of Petroleum Geologists Bulletin, 1975.

*CATALOGUE OF GEOIDAL VARIATIONS FOR SIMPLE SEAFLOOR TOPOGRAPHIC FEATURES*

Carl O. Bowin

This report presents a catalogue of theoretical geoidal variations for three types of structural features common to the earth's surface: seamounts, submarine ridges, and submarine trenches. These structures have been simulated by simple geometric shapes modeled in three dimensions. A computer program calculated the potential and gravitational variations over the models. Profile plots of geoidal variations and free-air gravity anomalies are presented over cross sections of the structures. The purpose of this catalogue is to provide a ready reference information set for comparison with satellite altimeter data for ocean areas.

Technical Report, prepared for the National Aeronautics and Space Administration.

Supported by: NASA contract NAS 6-2585.

*CRUISE DATA REPORT R/V Chain Cruise 115 LEG 5 SOUTHLANT EXPEDITION*

R. C. Groman, S. R. Gegg and J. D. Kroll

The R/V *Chain* Cruise 115 left Cape Town, South Africa for Leg 5 on March 23, 1974. Underway observations included magnetic, gravity, and 3.5 kHz bathymetric measurements throughout the leg; seismic reflection studies were done for 25% of the distance traveled. Stations were occupied for the *in situ* collection of pore waters (harpoon samples), piston and gravity coring, and heat flow measurements (thermal gradient). pH and alkalinity were measured on bottom waters of all harpoon stations. The location and operations carried out at each station are summarized in Table II. Figure 1 shows the navigation for this leg, plotted at 0.36 inches per degree of longitude (before reduction). The R/V *Chain* arrived at Rio de Janeiro on April 18, 1974.

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COLLECTION AND ANALYSIS OF SEISMIC WIDE ANGLE REFLECTION  
AND REFRACTION DATA USING RADIO SONOBUOYS

Sydney T. Knott and Hartley Hoskins

Information on velocities of compressional waves and thicknesses of layers in the oceanic sediments and basement can be gathered by use of sonobuoys to receive repetitive sound sources (sparkers and airguns) over wide-angle or oblique sound paths. In order to obtain data of sufficient quality to ensure accurate and reproducible results by this method, it is essential that proper techniques be used in the original data acquisition, recording of ancillary data, and playback and analysis of the records. Detailed instructions are provided for field data collection, and for subsequent data playback and analysis, including suggestions for recording formats and scales.

Technical Report.

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CRUISE DATA REPORT R/V Chain Cruise 115 LEG 7

J. D. Kroll, S. R. Gegg, and R. C. Groman

Leg 7 of R/V *Chain* Cruise 115 departed Recife, Brazil on May 22, 1974. The majority of the work was done on the eastern flanks of the Pernambuco and Rio Grande Plateaus. Five locations were chosen as sampling stations. At each of these five stations dredging was accomplished using the standard chain-bag dredge equipment. Table 2 summarizes the locations of the stations, and Figures 1A and 1B show their locations on Mercator charts. The underway program included 3.5 kHz bathymetric measurements, magnetic and gravity recordings. Seismic reflections were recorded for approximately 65% of the total distance covered during leg 7. Because of Brazil's 200 mile territorial limit, the magnetometer had to be secured whenever the ship was inside that limit. Consequently only a small amount of magnetics data was acquired during this leg. The R/V *Chain* docked in Fortaleza, Brazil on May 29, 1974.

TECHNICAL REPORT. Supported by: *National Science Foundation Contract IDOE GX-41960.*

UNIFORMLY-SENSITIVE LINE HYDROPHONES

S. T. Knott, F. R. Hess and R. T. Nowak

A uniformly-sensitive capacitive line hydrophone, dubbed WHOLINE, used as a towed broadband line hydrophone for seismic reflection profiling has produced significant increase in the signal-to-noise ratio.

When used in a broadband noise field (less than 10 to several kHz) to detect signals that both approach the array at near normal incidence and are also broadband, the directivity of a long continuous line offers a specific advantage over that of an equal length linear array of openly spaced discrete sensors. Discrete arrays in such a sound field develop side lobes of full sensitivity at a number

of frequencies at various angles to the array depending on the element spacing. In contrast, the side lobes characteristic of a continuous line are each successively reduced.

Technical Report.

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*COMPILATION OF RADIOMETRIC AGES FROM THE RYUKYU ARC REGION*

Carl O. Bowin

This report presents a compilation of radiometric ages of rocks from the Ryukyu Arc region. Pertinent information on radiometric ages for intrusive and volcanic igneous rocks, and for metamorphic rocks are tabulated and maps summarize their areal distribution.

Technical Report.

Supported by: *Office of Naval Research Contract N00014-74-C-0262; NR 083-004.*

PALEONTOLOGY / SEDIMENTOLOGY

*CENOZOIC RADIOLARIA FROM THE CENTRAL PACIFIC, DSDP LEG 33*

David A. Johnson

Radiolaria were identified in each of the five sites drilled on Leg 33. The locations of these sites are as follows:

<u>Site</u>	<u>Latitude</u>	<u>Longitude</u>	<u>Location</u>	<u>Water Depth (m)</u>	<u>Drilling Penetration (m)</u>
314	15°54.76'N	168°28.07'W	Johnston Island Trough	5225	45
315	04°10.26'N	158°31.54'W	Fanning Island Fan	4164	1034
316	00°05.44'N	157°07.71'W	Line Islands, Southern End	4464	837
317	11°00.09'S	162°15.78'W	Manihiki Plateau	2622	943
318	14°49.63'S	148°51.51'W	Tuamotu Islands	2659	745

Of these five sites, only one (Site 3178) recovered a substantial thickness of radiolarian-bearing sediment within a continuously cored interval. The remaining sites were spot-cored within the Cenozoic portion of the section. Pre-Eocene sediments at all sites were barren of radiolaria, except for small quantities of calcified radiolarian tests within certain intervals at sites 315A and 317A.

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*BIOLOGICAL UPTAKE OF DISSOLVED SILICA IN THE AMAZON RIVER ESTUARY*

John D. Milliman and Edward Boyle

Diatom production within the inner Amazon River estuary utilizes more than 30 micromoles/liter of silica, producing an estimated 15 million tons of opaline frustules annually. Many frustules that settle onto the shelf apparently dissolve at or near the sediment-water interface. Other frustules are transported landward, where they accumulate as diatomite layers within mud and sand bars.

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*DISSOLUTION OF ARAGONITE, Mg-CALCITE, AND CALCITE  
IN THE NORTH ATLANTIC OCEAN*

John D. Milliman

Direct measurements indicate that rapid dissolution of aragonite and Mg-calcite in the central Sargasso Sea begins 1,000 m deeper (3,500 and 4,400 m, respectively) than observed carbonate dissolution depths for these two minerals. Thus, whereas the rate of dissolution appears to be controlled by the degree of saturation, the carbonate content of sediment is also related to other oceanographic parameters.

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*COCCOLITHS IN CORES FROM BELLINGSHAUSEN ABYSSAL PLAIN  
AND ANTARCTIC CONTINENTAL RISE (DSDP LEG 35)*

Bilal U. Haq

Leg 35 of the Deep Sea Drilling Project drilled four sites, two on the Bellingshausen Abyssal Plain (322, 323) and two on the Antarctic Continental Rise (324, 325) during February/March 1974. Most of the sediments consist of terrigenous detritus derived from Antarctica and transported by bottom and turbidity currents and by ice-rafting. Some pelagic claystones were recovered in the bottom of holes 322 and 323 (Bellingshausen Abyssal Plain). Recovery of calcareous sediments was very poor (less than three meters in core 323 and a few thin layers in 325). These calcareous intervals contain poor to moderately well-preserved planktonic foraminifera and calcareous nannofossils.

The assemblages of Site 323 can be differentiated into two major types: a) the *Cruciplacolithus tenuis* dominated assemblage in the NP2 and lower part of NP3 zones, b) an *Ericsonia subpertusa-Coccolithus cavus* assemblage. The former is a relatively low diversity assemblage and is peculiar with respect to its dominance by a single species, i.e. *C. tenuis*. Elsewhere (e.g. northern Indian Ocean and mid-latitude Atlantic Ocean) the component species of the assemblages of equivalent age are essentially the same, but *C. tenuis* occurs only in rare to few numbers, the flora being dominated by *Ericsonia subpertusa* and *Coccolithus cavus*. The latter assemblage has elsewhere been observed, to dominate the mid and low latitudes of

the northern Indian Ocean and Tethyan region in NP3 zone. In the Atlantic Basin, this is the dominant middle Paleocene assemblage between 30°N-30°S, recorded from Caribbean and Gulf of Mexico sites as well as the central South Atlantic. Very similar assemblages have been described from western Greenland and Tasman Sea.

The present data from site 323 supports the earlier conclusion of Haq *et al.* (1974) that Danian assemblages were essentially cosmopolitan in the species composition. The differences were local and mainly in the relative dominance of component taxa. However, from the present data it would seem that the boreal *Prinsius martinii* assemblage that developed in NP3 zone was confined to the northern high latitudes only, since this taxon occurs in rare numbers in the material from Site 323. If the relative latitudinal position of various assemblages can be taken as the indication of their temperature preference, it can be concluded that during the Danian northern high latitudes were cooler than the southern high latitudes.

At Site 325 the possible Oligo-Miocene assemblage is dominated throughout by a single taxon, *Dictyococcites antarcticus* n.sp., occurring in abundances of up to 90% of total flora. This species shows similarities to *Dictyococcites scrippsae* and *Dictyococcites hesslandii*. *D. hesslandii* is a cosmopolitan species and is dominant in the higher latitudes of Oligocene. The dominance of *D. antarcticus* at Site 325 points to relatively low temperature for the period during which these sediments were deposited.

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ANTARCTIC SILICOFLAGELLATES FROM SOUTHEAST PACIFIC,  
DEEP SEA DRILLING PROJECT LEG 35

Bilal U. Haq and Anne Riley

DSDP Leg 35 silicoflagellates from the Bellingshausen Abyssal Plain and Antarctic Continental Rise are recorded from four sites drilled during early 1974. A high-latitude biostratigraphic zonation based on abundances of taxa is suggested for the Mio-Pliocene interval.

A considerable variation is seen in species size at different levels of Site 323. Cores 9 through 5 contain only very small-sized forms. In Cores 4 through 2 the average size of the same species has increased to almost double the average size in lower cores. The reason for such size variations are unknown. In general during periods of smaller average sizes, specimens are more numerous. One explanation of this phenomenon could be that these periods represent times of either enriched nutrient levels or even possibly higher temperatures. A higher nutrient level may lead to more rapid turn over and average smaller size but greater diversity. If the repeatability of such size variation could be demonstrated elsewhere and its constancy ascertained, this factor may eventually prove to be an important biostratigraphic and paleoecologic tool in the higher latitudes.

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EFFECTS OF ARID CLIMATE AND UPWELLING UPON THE SEDIMENTARY REGIME  
OFF SOUTHERN SPANISH SAHARA

John D. Milliman

The small influx of terrigenous sediment to the continental margin off southern Spanish Sahara is evidenced by the coarse carbonate sediments that cover the middle and outer shelf and by low concentrations of land-derived grains suspended within the shelf and slope waters. The main source of particulate matter in the surface waters is organic matter produced by coastal upwelling. Most of this material is recycled within the water column and on the bottom, and little accumulates within the bottom sediments.

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Miniacina miniacea: MODERN FORAMINIFERAL SANDS ON THE OUTER MOROCCAN SHELF

John D. Milliman

The attached foraminifera, *Miniacina miniacea*, is a major sedimentary component on the outer shelf off central and southern Morocco, particularly in water depths between 95 and 115 m, where concentrations generally exceed 40 percent of the carbonate fraction. Predominance of this species may be largely a function of the relatively great water depths which preclude optimal growth of other encrusting organisms.

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THE INFLUENCE OF UPWELLING ON SUSPENDED MATTER  
AND SHELF SEDIMENTS OFF SOUTHEASTERN BRAZIL

Colin P. Summerhayes, Ubirajara de Melo, and Henyo T. Barretto

Surface waters off southeastern Brazil contain very little terrigenous material in suspension, even off the mouths of major rivers. As a result of the low rate of supply of terrigenous sediment, calcarenites and live algal reefs are widespread on the middle and outer continental shelf. Upwelling near the coast and over off-shore banks, is associated with elevated amounts of suspensates, which are mainly planktonic and non-skeletal, and reach concentrations of 0.5 to 1.0 mg/l. Beneath the biologically productive upwelled surface waters there is remarkably little sedimentation of this organic matter. Also, although phosphorite deposits are usually associated with upwelling centers, there are no phosphatic sediments off southeastern Brazil. The absence of both organogenic sediment and phosphorite differentiates this coast from the areas of upwelling in the eastern Atlantic, and probably results from the high degree of oxygenation of upwelled water, which contains up to 6 ml/l of dissolved oxygen (more than three times as much as found in upwelling centers off northwest Africa, for example). Phosphorite and organically enriched sediment would be absent from paleo-upwelling centers of similar type, but these centers might be recognized through local enhancements of organic matter in the silt and clay fraction of marine sediments.

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A MULTIVARIATE SEDIMENTARY ENVIRONMENTAL ANALYSIS  
OF GREAT SOUTH BAY AND SOUTH OYSTER BAY, NEW YORK

Syed A. Ali, Richard H. Lindemann, and Peter H. Feldhausen

A multivariate statistical strategy for classifying paleo-environments (Park, 1974) was found to be effective for studying modern sedimentary processes in western Great South Bay and South Oyster Bay, New York. The 13 whole phi weight percent variables were tested for redundancy with R-mode cluster analysis. The samples were partitioned statistically into five environmentally significant facies using Q-mode cluster analysis: (A) sandy gravel, (B) sandy silt, (C) silty sand, (D) slightly gravelly sand, and (E) fine sand. An ordination depicted gradational relationships among the samples and the facies. It was used to evaluate the environmental and textural parameter gradients within the sample space. Interpretations obtained in this manner and by examination of the grain size curves suggest that these sediments were deposited by waves and currents on beaches and in wave zones (facies C and E), shoal areas (facies B), and tidal channels (facies A and D). Tidal currents, wave action and eelgrass control distribution of sediments within the two bays.

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THE PLIOCENE/PLEISTOCENE BOUNDARY IN DEEP-SEA SEDIMENT: STATUS IN 1975

William A. Berggren

Ideally chronostratigraphic boundaries, including the Pliocene/Pleistocene boundary should be *defined* by a reference to a specific lithic level in a continuously deposited marine section (the "golden spike"). Biostratigraphic, magnetostratigraphic and radiometric dating techniques should be employed in the *recognition* (=correlation) of boundaries on a global basis.

The integration of biostratigraphy magnetostratigraphy and radiometric dating suggests that the Pliocene/Pleistocene boundary is associated with the Olduvai Event (1.6-1.8 m.y.), although a more precise correlation cannot be made at this time. Multiple biostratigraphic criteria, many of which are geographically exclusive of each other due to climatically controlled provincialization, when calibrated to the paleomagnetic time-scale, allow the *recognition* (correlation) of the approximate position of the Pliocene/Pleistocene boundary over all extra-polar areas of the global ocean.

Climatic change (glaciation) plays no role in the fundamental definition of the Pliocene/Pleistocene boundary. Recent oxygen isotope studies reveal that there is no climatic event in the vicinity of the Olduvai event that enables a distinction between Late Pliocene and Pleistocene. This can only be achieved by studies utilizing one or more (preferably integrated) of the disciplines mentioned above.

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*CARBONATE SEDIMENTATION ON THE CONTINENTAL SHELF OFF SOUTHERN BRAZIL,  
WITH SPECIAL REFERENCE TO THE BENTHIC FORAMINIFERA*

Marco Aurelio Vicalvi and John D. Milliman

Changes in the oceanographic and sedimentological regime off southern Brazil are reflected in the carbonate and foraminiferal assemblages of the shelf sediments. North of Cabo Frio, carbonate-rich sands and gravels are characterized by *Halimeda*, bryozoans and coralline algae; tropical foraminifera include various species of miliolids and peneroplids as well as the encrusting *Homotrema rubrum*. Subtropical carbonate-rich sediments between Cabo Frio and Sao Paulo are primarily restricted to the outer shelf, and are dominated by coralline algae and increasing amounts of agglutinated foraminifera. Temperate carbonates off southernmost Brazil contain mainly barnacles and mollusks, with fewer agglutinated foraminifera.

Carbonates generally are not important in the middle shelf muds and inner shelf sands. Benthonic foraminifera in nearshore waters (particularly in temperate areas) are characterized by paucity in both species and individuals.

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*NORTHWEST AFRICAN SHELF SEDIMENTS:  
INFLUENCE OF CLIMATE AND SEDIMENTARY PROCESSES*

Colin P. Summerhayes, John D. Milliman, Scott R. Briggs,  
Alastair G. Bee, and Colleen Hogan

Shelf sediments off northwest Africa are latitudinally zoned. This zonation cannot be interpreted simplistically in terms of the distribution of climatic belts, or zones of relative humidity as previously thought. It results from the interaction of several factors some of which are indeed climatically controlled, like runoff, upwelling, swell development, and wind direction, but others of which are controlled by the "tectonic" framework, like the geology and physiography of both source and depositional area; in addition, late Quaternary history is important, most of the sediment being relict.

Chief result of these interacting factors is the formation of high-carbonate shell sand off Spanish Sahara and southern Morocco, and more muddy and terrigenous sediment further north. The relict carbonate sands developed (1) where the Holocene transgression was most rapid, (2) where the seabed was (and still appears to be) most disturbed by current and wave action (preventing the settling of fine terrigenous detritus), (3) where fluvial sources of sediment were not developed, and (4) where winds blow mainly onshore or alongshore. Modern aeolian dusts form terrigenous muds only off the southernmost Sahara, where winds do blow offshore; upwelling is intensified in the same region, resulting in organic enrichment of the mud deposits. Modern sedimentary processes also appear to have formed a mud belt off central and northern Morocco, not because rainfall is highest there, but because the physiography permits bypassing of the coastal zone by fine-grained detritus -- probably mainly during the flood season. Background data of this type may be of use in reconstructing the depositional environments of ancient shelf sediments.

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## EARLY CENOZOIC CALCAREOUS NANNOPLANKTON BIOGEOGRAPHY OF THE ATLANTIC OCEAN

Bilal U. Haq and George P. Lohmann

Biogeographic patterns of Early Cenozoic calcareous nannoplankton assemblages are delineated for the North and South Atlantic, Caribbean, and Gulf of Mexico. Nannoplankton assemblages are defined by Q-mode Varimax Factor and Oblique Factor Analyses of census data on 44 taxa from 113 deep-sea and land-based samples. Examination of their latitudinal distribution through time allows recognition of those assemblages which can be used as environmental indicators. Comparison of the distributions of contemporaneous nannoplankton assemblages with the distribution of the appropriate environmental indicator assemblage permits their classification as either low, mid, or high latitude nannoflora.

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## Eocene Benthonic Foraminiferal Biostratigraphy and Paleobathymetry of Orphan Knoll (Labrador Sea)

William A. Berggren and Jane Aubert

A benthonic foraminiferal fauna of about 80 taxa is recorded from the Eocene of Orphan Knoll (Labrador Sea).

The dominant supraspecific taxa are *Cibicidoides* (eight species), *Anomalinoidea* (6 species), *Pleurostomella* and *Bulimina* (five species each), *Stilostomella* (four species) and *Chrysalogonium* and *Ellipsodimorphina* (three species each). The numerically dominant specific taxa include *Nuttalides truempyi* (Nuttall), *Oridorsalis ecuadorensis* Galloway and Morrey), *Gyroidinoides girardana* (Reuss), *Buliminella grata* Parker and Bermudez, *Stilostomella curvatura* Cushman, *S. aculeata* Cushman and Renz, *Cibicidoides hercegovinensis* (de Witt Puyt) and *Bulimina orphanensis* sp. nov., described here.

The *Stilostomella-Pleurostomella-Nuttalides* assemblage suggests deposition at lower bathyal to abyssal depths (1000-2000 m) and supports an earlier interpretation by DSDP Leg 12 geologists that Orphan Knoll subsided rapidly to its present depth (1800 m) during Paleocene time.

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## PLATE TECTONICS AND PALEOCIRCULATION - COMMOTION IN THE OCEAN

William A. Berggren and Charles D. Hollister

Oceanic circulation is dependent upon dynamically interrelated aspects of geography and climate. Sequential changes in these two parameters during the past 200 m.y. have resulted in a complex history of oceanic circulation. Certain paleogeographic and climatic events have played a critical role in the evolution of global circulation patterns. The general picture is of deposition in tranquil oceanic environments during the Mesozoic under the influence of equable climates and oceanic thermal-haline homogeneity. In the Cenozoic continued continental dispersal and climatic deterioration (and latitudinal thermal heterogeneity) due to high latitude cooling (beginning 40 m.y. ago but particularly the last 10 m.y.)

led to accelerated surface and bottom water circulation, especially along western margins of ocean basins and the development of erosion and redeposition as a major sedimentary process. The Cenozoic activity taken in its entirety is referred to here as "commotion in the ocean".

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*STRONTIUM ISOTOPE, K, Rb, Cs, Sr, Ba,  
AND RARE EARTH GEOCHEMISTRY OF BASALTS FROM THE FAMOUS AREA*

William M. White and Wilfred B. Bryan

Ten basalts recovered from the FAMOUS area were analysed for  $^{87}\text{Sr}/^{86}\text{Sr}$ , K, Rb, Cs, St, Ba, and rare earth elements. The basalts show a wide range of major element chemistry. Strontium isotope ratios fall in the narrow range of .70288 to .70307, implying that these samples were derived from a homogeneous or uniformly mixed source. Trace element concentrations increase with differentiation index. However, the increase of most of these elements is greater than can be accounted for by fractional crystallization models based on major element chemistry, implying some other factor such as volatile transfer or small variations in source composition or degree of melting is involved. On the other hand, trace element ratios such as Rb/K, Ba/K, and (La/Sm)E.F. show little variation with differentiation index. Strontium isotope ratios, trace element ratios, and LIL element concentrations are higher in FAMOUS basalts than in typical MAR basalts, and fit the regional pattern observed by Schilling (1975) and White, *et al.*, (in press).

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*NILE DELTA: NATURE, EVOLUTION, AND COLLAPSE OF CONTINENTAL SHELF  
SEDIMENT SYSTEM, A PRELIMINARY REPORT*

Colin P. Summerhayes and Nancy Marks

On the continental shelf off the Nile Delta, fine nearshore sands give way seawards to prodeltaic muds which cover much of the middle shelf. Further seaward are relict terrigenous dune sands (middle shelf), and mixtures of relict and modern coralligenous sands (largely outer shelf) dominated by branching or encrusting coralline algae. Off the Rosetta and Danietta mouths of the river, prodeltaic muds have prograded seawards over the relict deposits. West of the delta, off Alexandria, terrigenous sedimentation controlled by the river, gives way to carbonate sedimentation much of which appears to be aeolian. The coralligenous sands off the delta probably formed in clear water either when sealevel was lower and Nile flow was directed to the deep sea through channels and canyons, or when sealevel was near present levels and Nile muds were confined near the coast by strong longshore currents.

Suspended matter studies show that at present, in the absence of river discharge, wave action and longshore current activity are the main forces controlling delta evolution. Storm waves effectively resuspend nearshore prodeltaic muds, which are moved away from the river mouths by east-moving currents.

Three main evolutionary phases can be recognised in the late Holocene history of shelf sedimentation off the Delta: (1) 'Classical', during Pharaonic times when there were several small distributaries, with a balance between wave action and sediment supply leading to development of a smooth arcuate coast paralleled offshore by narrow belts of deltaic sedimentation; (2) 'Channelized', from Pharaonic times to Aswan High Dam construction, when sediment supply was confined to two distributaries, leading to fluviially controlled prograding sedimentation at river mouths, and coastal erosion elsewhere; (3) 'Collapse', since Aswan High Dam construction, with wave erosion paramount in the absence of river discharge. A fourth phase, 'Decay', involving gradual subsidence of the delta and landward coastal retreat, can be predicted.

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#### ROLE OF CALCAREOUS ALGAE IN ATLANTIC CONTINENTAL MARGIN SEDIMENTATION

John D. Milliman

The extent to which calcareous algae contribute to continental margin sediments varies greatly with climate, sedimentary regime, and the type of algae. In the western Atlantic, coralline algae are major components in middle and outer shelf sediments of tropical and subtropical climates; codiacean green algae (primarily *Halimeda*) are restricted to the tropics. In the eastern Atlantic, corallines occur over a wider geographic range, but except for northwest Africa and the Mediterranean, do not reach the prominence seen in the western Atlantic; *Halimeda* is present only in the Mediterranean and is not an important sedimentary component.

Modern corallines accrete in water depths shallower than 70 m, the maximum depth limit depending partly upon the growth form (e.g. rhodolith versus maerl); but relict corallines (which grew during lower stands of sea level) locally occur in water depths greater than 180 m. The degree of reworking and intragranular cementation varies greatly with locality and age, but generally increases with increasing water temperature and with age of the sedimentary components.

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#### COCCOLITHS: PRODUCTION, TRANSPORTATION AND SEDIMENTATION

Susumu Honjo

The presence of coccolith ooze on the deep sea floor and the excellently preserved suspended coccoliths in the undersaturated water column is explained by accelerated and communal sinking of coccoliths and coccospheres in small zooplankton's fecal pellets. The community structure in the euphotic layer will be replicated in the underlying thanatocoenosis with high resolution without significant time-lag between the production and the deposition. The euphotic bioceonosis of coccoliths drift only a few hundred kilometers at the maximum while they descent at the rate of more than 150 m per day through 5,000 m of water column where the

variance of advection is approximately 5 km a day. At an Equatorial Pacific station it was estimated that 92% of coccoliths produced in the euphotic layer were thus being transported to the deep sea bottom. Coccolithophore production provides several grams of calcite to a square meter of sea floor per year. Coccoliths do not undergo significant change during passage through copepods and other planktonic grazers. The membrane which covers a copepod's fecal pellet is coherent particularly in cold water. It protects contents from spilling and from dissolution and accelerates sinking rates by providing a smooth surface. The membrane is biodegraded rapidly in warm water and its contents exposed. As such naked pellets sink, coccoliths are shed and suspended in aphotic water. The majority of freed coccoliths will be dissolved in the undersaturated water column before arriving at the bottom. Approximately 8% of coccoliths produced were estimated to be remineralized in the water column at the above-mentioned station if Peterson's (1966) dissolution rate of calcite is applicable.

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*LATE PALEOGENE (LATE EOCENE AND OLIGOCENE) BENTHONIC FORAMINIFERAL BIOSTRATIGRAPHY AND PALEOBATHYMETRY OF ROCKALL BANK AND HATTON-ROCKALL BASIN*

William A. Berggren and Jane Aubert

Oligocene benthonic foraminiferal assemblages from Rockall Bank (DSDP Site 117) and Hatton-Rockall Basin (DSDP Site 116), are recorded, compared and discussed. A small Upper Eocene assemblage at Site 116 is also recorded. Dominant Late Eocene elements include *Nuttallides truempyi* (Nuttall) and *Obangularia* sp. There is a marked faunal similarity between the sites in the Oligocene. Dominant elements are *Heterolepa mexicana* (Nuttall), and *Siphonina tenuicarinata* (Cushman), *S. advena* (Cushman), and common accessory species include *Planulina renzi* Cushman and Stainforth, *P. marialana* Hadley, *Gyroidinoides girardanus* (Reuss), *Oridorsalis ecuadorensis* (Galloway and Morrey) and *Cibicidoides trincherasensis* (Bermúdez). Sporadic, but persistent, occurrences of stilostomellids, pleurostomellids and uvigerinids support previous interpretations of a middle bathyal depth of deposition during the Late Paleogene at these two sites. Neritic faunal elements characteristic of the Oligocene of northwestern Europe occur in the Upper Oligocene of Hole 117 together with the normal bathyal fauna and may reflect episodic tectonic movements on the western flank of Rockall Bank.

Supported by: *Mobil Oil Contract 1472.*

*OCEANOGRAPHY AND SUSPENDED MATTER OFF THE AMAZON RIVER FEBRUARY-MARCH 1973*

John D. Milliman, Colin P. Summerhayes and Henyo T. Barretto

The hydrography of surface waters in and near the Amazon River in February and March of 1973 was indicative of "flood" conditions, both in terms of the off-shore extension of the freshwater plume and the high concentrations of suspended matter within the river water. While the net transport of Amazon water was NW (due to the Guiana Current), seasonal changes in wind direction resulted in formation of a nearshore counter current along the Pará coast.

More than 95% of the terrigenous sediment within the Amazon surface waters settles out in the river mouth, before salinity reaches 3 ‰. Most of this

sediment is resuspended by tides, waves and currents; practically no terrigenous sediment appears to escape offshore.

The prime components of suspended matter in the brackish water plume off the Amazon are diatom frustules. Contrary to the suggestions of other workers, Amazon outflow markedly increases the fertility of shelf waters. However, the high production of diatoms is not reflected in the sediments, probably due to rapid recycling as well as to NW transport of frustules by the Guiana Current. Although Amazon-borne silica is initially removed by biologic means, recycling releases it; the ultimate fate of the silica is unknown.

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*SEQUENTIAL DEPOSITION OF AUTHIGENIC MARINE MINERALS AROUND NEW ZEALAND:  
PALEOENVIRONMENTAL SIGNIFICANCE*

G. P. Glasby and Colin P. Summerhayes

Phosphate deposits which apparently formed during the Miocene climatic optimum are widespread on the Chatham Rise and Campbell Plateau, and on seamounts in the north Tasman Sea. They formed under oxidising conditions by the phosphatisation of older or contemporaneous foraminiferal oozes (Campbell Plateau and Chatham Rise) and coral limestones (Tasman Sea). The phosphorites of the rise and plateau were formed where current activity was sufficiently strong to prevent normal sedimentation, and now form lag deposits. After the Miocene, phosphorite formation ceased and was followed by manganese oxide deposition where conditions were highly oxidising on the eastern Campbell Plateau and north Tasman seamounts, and by glauconite formation in the much less oxidising environments of the western Campbell Plateau and the Chatham Rise. The manganese deposits are not volcanogenic, as was formerly thought, but formed by slow precipitation from well oxygenated sea water.

Published in: *New Zealand Journal of Geology and Geophysics*, 18, 1975.

**MARINE POLICY AND OCEAN MANAGEMENT**

*TECHNOLOGICAL TRANSFER IN MARINE SCIENCE*

Leah J. Smith and David A. Ross

Technology transfer and assistance in the marine sciences will benefit oceanographers in developing countries as well as be satisfying to those from countries having developed marine science capabilities. In many developing countries interest in marine science is motivated by hopes to exploit marine resources. The difference between applied and basic research in marine science is more imagined than real, and basic research programs proposed by scientists from a developed country may meet the interests of scientists and politicians in developing countries.

Some successful past programs and future possibilities are described as well as suggestions as to how to make these programs more successful in the future.

Supported by: *Marine Policy and Ocean Management Programs of the Woods Hole Oceanographic Institution.*

## SEABIRDS

A NOTE ON SEABIRD OBSERVATIONS BETWEEN DAKAR AND CAPE TOWN:  
R/V Chain Cruise 115, December 1973-January 1974

Colin P. Summerhayes

En route between Dakar and Cape Town, during the southern summer of 1973-1974, the greatest number of species and generally the largest numbers of seabirds were seen over the productive upwelled waters of the Benguela Current off southern Africa. The numbers of seabirds seen at this time were less than during the winter months off southern Africa. These observations tend to confirm that the movements of migrant species are concentrated in the Benguela Current region, rather than over the open ocean.

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PROJECT FAMOUS:  
ORIGIN, PROGRAMS, TECHNIQUES

*PROJECT FAMOUS: OPERATIONAL TECHNIQUES AND AMERICAN SUBMERSIBLE OPERATIONS*

Robert T. Ballard and Tjeerd H. van Andel

The diving operations associated with Project FAMOUS utilized an advanced deep-diving submersible with many capabilities including a highly accurate positioning system. Since the capabilities and mode of operation of this submersible in the context of a major research project are not well-known, the operational techniques are described in some detail. Project FAMOUS dive operations relied upon extensive regional and intermediate scale surface ship studies prior to and during the dive period. These provided the basic geological and geophysical context in which the studies by the submersible *Alvin* were placed. The detailed bathymetric charts provided by the U. S. Navy on the basis of multi-narrow-beam echosounding, precision submersible navigation, advanced submersible data logging, and post-cruise processing systems furnished an accurate frame of reference for the dive operations as well as for the subsequent studies of the tectonic and volcanic processes.

Supported by: *National Science Foundation Grants GA-35976, GA-41694, and GX-36024.*

*PROJECT FAMOUS: ITS ORIGIN, PROGRAMS, AND SETTING*

James R. Heirtzler and Tj. van Andel

Project FAMOUS was organized to provide data on the details of the Mid-Atlantic Ridge spreading process. From 1971 until a series of manned submersible dives to the inner Rift valley floor took place in 1974, numerous cruises were undertaken to define the chief characteristics of the American and African plates and the line of their common origin. New technology was required and used on several cruises.



At the same time major outfitting of submersibles and training of submersible diving scientists and pilots were undertaken.

A detailed picture of the inner rift valley has emerged between two fracture zones at latitudes of about 36°30' and 37°N. The width of the inner valley floor here is approximately 1 to 5 km with the narrow part nearly midway along this 40 km long inner valley. There is a series of low, apparently young hills along the center line of the valley floor, which are intensely fissured. Most of the American submersible dives occurred on the floor of this rift valley between the latitudes of 36°47' and 36°50'N.

On the north this rift valley segment is offset approximately 20 km to the east (right laterally) by fracture zone A. The dives by French submersibles were primarily in this fracture zone and in the rift valley floor north of the American dive area.

To the south the rift valley segment is offset about 20 km to the west by fracture zone B. Two of the American dives took place there. Although in these fracture zones the zone of sheared rocks has a width of nearly 20 km, the currently active part of each fracture zone is less than 1 km wide.

Supported by: *National Science Foundation Grants GX-36024 and DES-1593.*

## HISTORICAL NOTES

### *EARLY DAYS OF MARINE GEOLOGY (1937-41) -- THE WAY IT WAS*

Robert S. Dietz and Kenneth O. Emery

Marine geology before World War II was primitive in contrast with the sophisticated equipment and computers of the present. This meant that the marine geologists had to invent their own hardware and they tended to be good observers of the whole field of oceanography. Possibly the changes that have occurred during the past 40 years will be small compared with those that may occur during the next 40 years.

## MARINE RESOURCES

### *SOME CHARACTERISTICS OF NATIONS*

Kenneth O. Emery

A comparison of groups of nations shows that the industrial and communist nations are much fewer in number than underdeveloped ones, but they have about the same total land areas and populations and they greatly lead in gross national product (GNP), income per capita, literacy, uses of fossil fuels, and production of fossil fuels, important industrial minerals, and food. The underdeveloped nations are rapidly becoming more numerous, progressively smaller, and most are economically and militarily weak. This is an unstable situation that probably cannot long exist.

What is a Nation?

At the end of 1975 the United Nations had 144 members, but its statistics on population, production, and resources recognized many more nations. At least 216

nations have statistical records, and 196 have their own unique coinages. The author has some knowledge of many of them, having conducted oceanographic work off the coasts of more than 100 and visited the land areas of 65.

In large part, the criteria for identifying a nation as such are artificial, dependent upon agreement of inhabitants or force from inside or outside the unit. The transitory nature of nations is illustrated by the recent disappearance of Nepal, Sikkim, and South Viet Nam from the list, and by the possible disappearance or fragmentation of Angola, Comoro Islands, Laos, Lebanon, Portuguese Timor, and Spanish Sahara before this article is published.

Published in: *Illinois Business Review, Econ. & Bus. Research, University of Illinois* 33, 1975.

Supported by: *Bigelow Chair.*

*OFFSHORE PETROLEUM: PROBLEMS IN SCIENCE, ENGINEERING,  
ECONOMICS, POLITICS, AND EMOTION*

Kenneth O. Emery

The values and dangers of offshore petroleum production have been described in such an enormous outpouring of written and spoken words during the past five years that this one additional article can say little that is new. I can only present some of my views and hopefully clear up a few popular misconceptions.

Published in: *Massachusetts Institute of Technology Technology Review*, 78, 1975.

*NEW OPPORTUNITIES FOR OFFSHORE PETROLEUM EXPLORATION*

Kenneth O. Emery

Much oil and gas remains to be discovered on the ocean floor using geological mapping and geophysical tools such as seismic reflection and refraction, magnetics, and gravity. Success in this search requires the scientist to be almost equally adept at politics, finance, technology, and science.

Published in: *Massachusetts Institute of Technology Review*, March/April 1975.

*OIL AND GAS RESOURCES*

Kenneth O. Emery

Estimates of undiscovered oil and gas resources by the National Academy of Sciences Committee on Mineral Resources and the Environment were based upon five different methods previously published by interested workers. The results were rather similar and showed that the resources of oil and gas are far smaller than those for coal and oil shale, on which increased effort must be spent to solve the energy problems of the United States.

Published in: *Science*, 188, 1975.

*MINERAL RESOURCES AND THE ENVIRONMENT*

Kenneth O. Emery

The subpanel on Fossil Fuel Resources, part of the Committee on Resources and the Environment, concluded that the proved reserves of oil total only about ten times the 1973 production in the United States, and that the undiscovered resources of it are only three times greater. This means that a major effort must be made to obtain the energy from oil shale and coal, both of which contain energy equivalent to several thousand times that in oil.

Published by: *National Academy of Sciences, Washington, D.C. 1975.*

# OCEAN ENGINEERING

OE-1

DEPARTMENT OF OCEAN ENGINEERING  
Earl E. Hays, Department Chairman

## ACOUSTICS

*FLUCTUATIONS OF NARROW-BAND SOUND AMPLITUDES  
FROM LONG-RANGE TRANSMISSIONS IN THE DEEP ATLANTIC OCEAN*

Lincoln Baxter, II, and C. Y. Yang

For transmission paths between a fixed acoustic source at 527-m depth near Eleuthera and a fixed receiver at 1723 m near Bermuda, G. E. Stanford (J. Acoust. Soc. Am. 55, 968-977 (1974)) has shown that the spectrum of fluctuations in acoustic intensity is nearly flat up to 3 cycles/h and drops off as  $1/f^3$  above this frequency. For comparison with internal gravity wave disturbances of the sound velocity profile, we have analyzed amplitude fluctuations of transmissions from floats deployed as part of the 1973 series of Mid-Ocean Dynamics Experiments (MODE). These floats carrying 30-W input, 270-Hz sound sources pulsed for 1.67 sec at 3-min. intervals were released to drift near 28°N, 70°W at a depth of approximately 1500 m. The transmissions were received by fixed hydrophones (MILS system), located on the sound channel axis on the slopes of Eleuthera and Grand Turk. We find a spectrum similar to that of Stanford except that the  $1/f^3$  characteristic begins at 1 cycle/h. For each experiment, this rolloff frequency coincides approximately with the Brunt-Väisälä frequency at the turning points of those SOFAR paths with minimum excursion from the axis.

Published in: *J. Acoust. Soc. Am.*, 58. 1975.

Supported by: *Office of Naval Research contract N00014-70-C-0205; NR 083-325.*

*THE ACODAC AMBIENT NOISE SYSTEM*

David S. Bitterman

The ACoustic DATA Capsule (ACODAC) system was designed to obtain long term, unattended measurements of the ambient acoustic noise in the deep ocean. The instrument consists of a 40" diameter pressure vessel containing a 7-channel low speed analog tape recorder, a time code generator, automatic gain ranging data amplifiers and an acoustic telemetry system. An associated vertical array of six hydrophones spaced at various depths along an electromechanical cable extends from near the surface to the sea floor. Simultaneous recordings over the frequency range 10-400 Hz can be made from all hydrophones for periods of up to 30 days in water depths to 18,000 feet.

The instrument has been deployed sixteen times during the past two years by the Woods Hole Oceanographic Institution with a total accumulation of approximately 850 hydrophone days of data. A brief description of the associated data reduction system is included along with some examples of the 1/3 octave and narrow band spectrum analysis performed on data from one deployment.

Supported by: Technical Report prepared for *The Office of Naval Research under contract N00014-71-C-0057; NR 292-047.*

*MICROEARTHQUAKE LOCATION USING A MAXIMUM LIKELIHOOD PROCESSOR*

H. David Leslie, Robert P. Porter, and Robert C. Spindel

Sonobuoy arrays located over the Mid-Atlantic Ridge have been used to measure the spatial coherence of sound radiated from sea quakes and provide refined estimates of epicenter locations. These measurements were made with array elements separated by two km and tracked to an accuracy of 20 m. Spatial coherence, the normalized cross-spectral density, has been found to be as high as 0.7 at 14 Hz, and to be typically about 0.5 between 16 and 60 Hz. Short range events are significantly more coherent than long range events whose onset is smeared in time. Significant processing gain has been achieved using a maximum likelihood array processor. Improvement, over the conventional delay and sum processor, of as much as 4 to 1 has been obtained. The resolving power obtained with these arrays is consistent with measured spatial coherence.

Supported by: *Office of Naval Research Contract N00014-74-C-0262; NR 083-004.*

*TRAVEL TIME ALONG MODIFIED RAYS*

Edward L. Murphy and Michael A. Schoenberg

For a 'plane' harmonic sound wave propagating in a stratified inhomogeneous medium such that a corresponding ray element has a vertex near a boundary or near an extremum in the sound speed, the wave, upon reversal, undergoes a phase change  $\phi(\omega, \mu)$  where  $\mu$  may be identified as the sine of the angle of incidence,  $\theta_0$ , and  $\omega$  is the radial frequency. In earlier work, it has been shown that the ray segment after reversal is displaced in range an amount proportional to  $\partial\phi/\partial\mu$ . In this paper the travel time of a pulse along such modified ray paths is determined. It contains contributions from  $\partial\phi/\partial\mu$  and from  $\partial\phi/\partial\omega$ . An example is presented for which arrival time as a function of frequency at a fixed range has been computed.

Supported by: *Office of Naval Research Contract N00014-70-C-0205; NR 083-325.*

*LONG-RANGE ECHO-SOUNDING WITH A CHIRP SOURCE*

Marshall H. Orr, Robert C. Spindel, Robert P. Porter

An experiment has been performed to determine the applicability of coherent signal processing techniques to a long range, low-frequency, side-looking, bathymetric survey system. A linear FM sweep of 280 Hz center-frequency, 10 Hz bandwidth and 20 sec duration was produced by a source at depths between 120 and 150 m towed parallel to the Blake Escarpment at a range of about 250 km. Reflected signals were received by a line array towed at depths ranging from 765 to 825 m. The received signals were passed through a digital pulse compressor and averaged. Groups of the received signals were easily identified as reflections from the Blake Escarpment. The experiment has shown that coherent signal processing techniques are applicable to low-frequency side-looking bathymetric survey systems.

Supported by: *Office of Naval Research Contract N00014-70-C-0205; NR 083-325.*

*ACOUSTIC SIGNATURES FROM DEEP WATER IMPLOSIONS OF SPHERICAL CAVITIES*

Marshall H. Orr and Michael A. Schoenberg

Hollow glass spheres of various sizes have been preweakened to implode at ocean depths of approximately 3 km and sunk using chain weight. Acoustic signals generated from the implosion of these spheres have been analysed. Pressure signatures, energy density spectra and total acoustic energy in the frequency band 96-5000 Hz are presented. The signatures of all the implosions have many features in common. Basically each consists of a low flat negative pressure pulse followed by a sharp positive pressure spike of roughly .2 msec duration. The efficiency of the conversion of available potential energy to radiated acoustic energy is approximately 18%. Total radiated acoustic energy for spheres of 43.2 cm diameter imploding at 3 km depth is about 53 db re 1 J. Preweakened glass spheres show promise as a tool in the study of the sedimentary structure of the ocean bottom due to the impulsive character of the signal that is radiated upon implosion.

Supported by: *Office of Naval Research Contract N00014-70-C-0205; NR 083-325.*

*ENERGY EVALUATION OF WIDE-BAND SOFAR TRANSMISSION*

Robert P. Porter and H. David Leslie

Transmitted energy levels for wide-band SOFAR transmission are calculated for arbitrary sound-speed profiles using ray-mode analysis (R. P. Porter, *J. Acoust. Soc. Am.* 54: 1081-1091 (1973)). The analysis of the received field has been generalized to include arbitrary normal modes and range-varying, sound-speed profiles. It is shown that computations of wide-band propagation based on ray-mode analysis require an order of magnitude fewer calculations than do calculations by harmonic analysis. A computer code has been developed and used to estimate the wide-band loss for profiles from the Mediterranean and the North Atlantic. Comparisons with continuous tone, normal-mode calculations yield agreement to within 3 db.

Published in: *J. Acoust. Soc. Am.*, 58. 1975.

Supported by: *Office of Naval Research Contract N00014-70-C-0205; NR 083-325.*

## COMPUTERS / DATA PROCESSING

*BIT SERIAL TRANSMISSION FOR DATA ACQUISITION*

Kenneth R. Peal

A serial multichannel multiplexing system which can be readily reconfigured for different tasks has been constructed and tested. The system has all of the advantages of bit serial transmission, uses the American Standard Code for Information Interchange (ASCII), and has been interfaced to a computer with a serial teletype port.

High speed data transmission, simple wiring requirements, and insensitivity to electrical noise make ASCII bit-serial transmission ideal for shipboard data acquisition systems. Integrated circuits for conversion between TTL (transistor



transistor logic) and serial ASCII modes are inexpensive, readily available and easy to use.

Arguments are presented to encourage the oceanographic community to standardize on serial ASCII data transmission for shipboard instrumentation.

Supported by: *National Science Foundation Grant OFS-75-02938.*

*EVALUATION OF A FLEXIBLE DISC OPERATING SYSTEM  
FOR HEWLETT-PACKARD COMPUTER SYSTEMS*

Christopher F. Polloni

The shipboard computer systems group has evaluated the performance of a Daconics flexible disc memory. The unit was installed on a shore-based Hewlett-Packard 2116A computer. It was used extensively (347 hours) and proved to be completely compatible with the hardware and software used.

Later the unit was installed on the R/V *Knorr* for additional tests. These provided the first at-sea performance evaluations. During this cruise the unit was used for 182 hours with the Flexible Disc Operating System executive as well as with the diagnostic. Despite adverse weather and extreme laboratory temperature and humidity variations, the unit performed with no difficulty.

As a result of this evaluation, four units have been installed on the shipboard computer group systems.

Supported by: (Technical Memorandum) *National Science Foundation Grant OFS-72-02738.*

*COMPUTER PROGRAM FOR REAL TIME DATA ACQUISITION WITH  
THE MULTIPLE OPENING/CLOSING NET AND ENVIRONMENTAL SENSING SYSTEM (MOCNESS)*

Christopher F. Polloni

MOCNESS AQUIS (MAQUI) is a modified version of the standard CTD (Conductivity, Temperature and Depth) acquisition program. It was developed to support the biological research being performed by Peter Wiebe aboard R/V *Chain* for Cruise 125, August, 1975.

The program was used successfully and logged a total of 22 tows with MOCNESS. This document bears proof of the flexibility of the CTD device and its possible diverse application.

Supported by: (Technical Memorandum) *National Science Foundation Grant DES-74-0783.*

## CORROSION/FOULING

*CONTROL OF MICROBIAL SLIME FILMS IN OTEC HEAT EXCHANGERS*

Stephen C. Dexter

The conditions in terms of time and depth of exposure under which biofouling occurs have been measured for a typical subtropical open ocean site. Some results of recent research on a new method of slime film control involving manipulation of the substrate wettability rather than the use of leachable toxicants are presented, and these results are discussed in the context of controlling biofouling on the sea water side of OTEC (Ocean Thermal Energy Conversion) heat exchanger tubing.

Supported by: *H-83609-A, Amendment No.3 and H-801B from the National Data Buoy Office and a Grant from the Alcoa Foundation.*

*MINERAL DEPOSITION IN CURRENT METER BEARINGS*

Stephen C. Dexter, John D. Milliman and William J. Schmitz, Jr.

Carbonate deposits (siderite, aragonite and calcite) have been identified within current meter bearings. These deposits were observed to inhibit and even prevent the response of sensors mounted on the bearings. The mechanism of precipitation of these minerals is described, with particular reference to the increased reaction rate found when an electrical path is permitted between a sacrificial anode and a stainless steel bearing (which becomes a cathodic crevice). Future deployments at sea of instruments with cathodic crevices should be carefully evaluated in light of the deposition mechanism described.

Published in: *Deep-Sea Research*, 22, 1975.

Supported by: *Office of Naval Research Contract N00014-66-C-0241;NR 083-004.*

*INFLUENCE OF SUBSTRATE WETTABILITY ON THE ATTACHMENT OF MARINE BACTERIA TO VARIOUS SURFACES*

Stephen C. Dexter, James D. Sullivan, Jr., Jesse Williams, III, and Stanley W. Watson

The effect of the initial substrate surface condition, as indicated by the critical surface tension for wetting, on the rate of attachment of marine bacteria to a variety of solid surfaces has been measured. The techniques used to determine the number of bacteria attached per unit surface area were a lipopolysaccharide test utilizing *Limulus* lysate and direct examination of the surface by scanning electron microscopy. The results obtained by the two techniques are compared and their significance to the control of microbiological slime film formation (microfouling) is discussed.

Published in: *Applied Microbiology*, 30, 1975.

Supported by: *Alcoa Foundation and Atomic Energy Commission Contract AT-(11-1)-3565.*

## MOORINGS

*STRUMMING TESTS ON TWO FAIRED CABLES*

Earl E. Hays, Richard T. Nowak and Paul R. Boutin

Measurements are presented of the transverse accelerations of faired and un-faired cables, suspended in water sixty feet deep with currents up to one knot while under 1000 lbs. tension. Four types of fairing were tested on 3/8" steel double armored wire rope, and one type was tested on 3/4" fibre line. The greatest reduction in strumming was obtained by use of many transverse fibres about eight times as long as the line diameter. There is large spread in the measurement results.

Printed as a Technical Report.

Supported by: *Office of Naval Research Contract N00014-71-C-0057; NR QLR-047.*

*PREDICTION AND MEASUREMENT OF THE STABILITY OF THE IWEX TRIPOD MOORING*

Narayana N. Panicker and Dennis W. Schmidt

The three-dimensional array of sensors for the Internal Wave Experiment (IWEX) was supported on a tripod mooring rising from the sea floor to a height of 5 km in mid-ocean of 5-½ km water depth. The mooring was so designed that the current-induced motions of the mooring would be small. Computer simulation was used for optimizing the mooring design to achieve this purpose.

Nine precision pressure recorders were deployed at selected positions on the mooring and the results of analysis of the records are presented. The local tide time series is generated and subtracted from the pressure records to obtain the vertical excursions of the mooring. A five-term expression is used to convert pressure measured in decibars to depth in meters. The predicted displacements and the measured values are compared and found to agree. The mooring motion was found in general to be small enough to contribute insignificant noise to the velocity measurements.

Printed as a Technical Report.

Supported by: *Office of Naval Research Contract N00014-74-C-0262; NR 083-004.*

*DEEP OCEAN CURRENT MEASUREMENTS SYSTEM*Robert G. Walden, Clayton W. Collins, Jr., Peter R. Clay,  
Patrick O'Malley, Walter E. Schott, III

A need for reliable subsurface deep ocean current data for the design and construction of fixed ocean facilities was defined by Navy Ocean Facilities Program engineers in 1973. The logic for the measurement requirements was predominantly based on the predicted behavior of subsurface moored structures in deep ocean current regimes. A technical report has been completed containing a design of an optimized single-point current meter mooring using commercially available components to meet the Navy requirements. The following design efforts are described:

(1) definition of a deep ocean design environment, (2) survey of commercially available current meters, (3) studies of mooring-meter-environment interaction, (4) selected subsystem tests, (5) system trade-off studies, and (6) formulation of designs.

Specific information is contained on components and their arrangement for the reliable measurement of deep ocean currents. The designs are such that the current data obtained will be sufficiently accurate to serve as a basis for the design of deep ocean fixed facilities such as subsurface moorings or platforms. Confidence in the results is sufficiently high so that the Navy is in the process of procuring the recommended components at this time. These systems are expected to serve as a basic deep ocean current measurement tool for the next five to ten years. The design methodology provided can be adapted for the development of other current measurement systems. Similar procedures can be used to produce shallow site or near-surface systems.

Designs for optimized deep ocean current measurement systems are presented, and the rationale for deriving these designs is described. Distributed and centralized buoyancy, aramid fiber lines, and specific current meter types are among the recommendations. Field data, laboratory results, and computer study findings are provided. Options are provided so that rational decisions can be made on the choice of mooring design as a function of performance requirements.

Supported by: *Naval Facilities Engineering Command Grant 0080, Washington, D.C.*

#### *DEEP-SEA LINES FISHBITE MANUAL*

Bryce Prindle and Robert G. Walden

Since the report of Stimson (1964), fishbite has been recognized as a major cause of failure in deep-sea moored stations. A considerable amount of information on the subject has been developed and is available from widely scattered sources. It is the purpose of this manual to assemble and correlate as much as possible of that body of knowledge in a form which will make it generally available and useful to persons involved in the establishment and maintenance of deep-sea moored stations, and where lines are used in deep-sea waters for other purposes.

Examples of typical damage and techniques of identifying such damage are given. A study of fishbite damage to mooring lines from many parts of the world was made to identify the causative organisms where possible, and to determine their geographical, depth and temporal distribution. Current theories of the predisposing factors such as line motion, line characteristics and lure attraction are discussed. The effect of water temperature and currents are considered.

Methods of testing candidate armor materials were developed and specifications for a suitable armor given. Finally a design is suggested which will reduce the chance of line damage.

Supported by: *National Oceanic and Atmospheric Administration (NOAA) Data Buoy Office, Bay St. Louis, Mississippi (under Contract H83609A) and the Office of Naval Research, Code 480.*

## SUBMERSIBLES

## ALVIN BATTERY CHARGING PROCEDURES

David S. Hosum, John D. Donnelly and William F. Page

This publication documents the ALVIN battery characteristics, operation instructions and maintenance procedures. The step-by-step procedures for putting batteries in service, normal charging, equalizing and major maintenance are included. It is expected that this publication will be updated as required to provide current information.

Technical Memorandum

Supported by: *National Science Foundation Grant OFS-74-01038.*

## ALVIN GYROCOMPASS PERFORMANCE REPORT

David S. Hosum and John D. Donnelly

Two gyrocompasses were evaluated on ALVIN during the 1974 FAMOUS operation. This at-sea evaluation calculated average and peak errors for both the Gyrosystems, Inc. and Sperry Marine Systems Co. compasses while at sea using the R/V LULU gyrocompass and the R/V Knorr gyrocompass as references. The Sperry compass had an average error of 1.4° and a peak error of 8°. The Gyrosystems compass had an average error of 4.6° and a peak error of 21°. The Sperry compass was very reliable at sea and the Gyrosystems unit was not reliable for at-sea operation.

Technical Memorandum

Supported by: *National Science Foundation Grant OFS-74-01038.*

## DSRV ALVIN WEIGHT REPORT, 1975

Arnold G. Sharp

Weight and stability information has been updated for the research submarine ALVIN for 1975. The report includes results of the computations programmed for the Institution's XDS Sigma-7 computer, observed values resulting from the tethered trim dive and inclining experiments, and miscellaneous stability calculations. Principal results are the weight, displacement, and longitudinal and vertical components of the BG and GM distances, for the complete submersible, and for various major sub-assemblies.

Technical Memorandum

Supported by: *Office of Naval Research Contract N00014-73-C-0097; NR 265-107.*

*A PENDULUM INCLINOMETER FOR USE WITH SMALL DEEP-SUBMERSIBLES*

Arnold G. Sharp and James R. Sullivan

The authors developed a pendulum inclinometer suitable for use with small deep submersibles or surface craft. The instrument uses a relatively short heavy pendulum and a viscous damping system for minimizing the effects of unwanted oscillatory motion. The pendulum relative motion is transmitted to the dial pointer through a flexible cord. The mechanism is designed so that the inclinometer gives a direct reading of the tangent of the angle of inclination. Adjustments are provided for levelling the instrument and for setting the dial to zero. Upper and lower clamping devices protect the pendulum suspension from damage during transit. The inclinometer has been used successfully in recent inclining experiments for the small research submarine *Alvin*.

Supported by: *Office of Naval Research Contract N00014-73-C-0097; NR 265-107.*

*ALVIN OPERATORS MANUAL*

Lawrence A. Shumaker

This publication was written to provide a single point reference for the normal and emergency operating procedures for the Deep Submersible Research Vehicle *Alvin*. It also includes some operational data of use to the pilot, and instructions for passengers in the event of an emergency.

Technical Memorandum

Supported by: *National Science Foundation Grant OCE-74-01038*

## NAVIGATION

*PERFORMANCE ANALYSIS OF DEEP OCEAN ACOUSTIC NAVIGATION SYSTEMS*

Robert C. Spindel, James L. Durham and Robert P. Porter

Two distinct acoustic methods are used to provide precise navigation at sea over areas of approximately 100 km<sup>2</sup>. Both methods position via acoustic transmission from a set of moored transponders or beacons. When the elements of the reference net are operated in a transpond mode the system is called a pulse positioning system; when operated in a continuous mode the system is known as a Doppler system. A combined navigation scheme which capitalizes on the attributes of both the pulse and Doppler modes is under development. It will be capable ultimately of positioning a platform with respect to the reference net with an error of 1 to 2 meters, and of repositioning a platform within 10 cm of a previous fix in 5 km depth water. In this paper we present a performance analysis of the pulse-Doppler system in which we consider the characteristics of the system receivers in detecting pulse and Doppler information. Factors affecting performance such as signal level, receiver bandwidth, ambient sea noise and platform motion are discussed. Comparisons are made between optimum and typical performance.

Published in: *Proc. of the IEEE OCEAN '75 (Institute of Electrical and Electronic Engineers) Conference, Halifax, Nova Scotia.*

Supported by: *Office of Naval Research Contract N00014-75-C-0661; NR 294-017.*

NAVIGATION MULTIPLEXER:  
GENERAL DESCRIPTION, OPERATION AND SERVICE MANUAL

Kenneth R. Peal

A multiplexer is a device which sends several messages through one channel. In this case, the messages are readings from electronic instruments and the channel is a single pair of wires which goes to a teletype or a computer. As a result the data from several instruments are recorded on a teletype or transmitted to a computer for processing. Since the instruments in this application are radio navigation receivers, the system is called a navigation multiplexer. However any instrument with digital readouts may be used.

A system was designed and constructed at Woods Hole Oceanographic Institution using Analog Devices Serdex modules which use time-of-day information to allow recordings from several navigation receivers to be made at preselected intervals. In addition the time is recorded together with the navigation data. Thus the system performs unattended, automatic data logging.

Published as: *Technical Memorandum No. 2-75.*

Supported by: *Information Processing Center, Woodr Hole Oceanographic Institution.*

AN ACCURATE ACOUSTIC NAVIGATION SYSTEM WITH REAL TIME DISPLAY

Kenneth R. Peal and Allan H. Driscoll

An acoustic navigation system has been designed which provides real time display of ship position as well as position and depth information for any kind of tethered or free underwater package. Accuracies in the tens of meters are obtained using commercially available equipment: pulsed transponders moored near the ocean floor; a relay transponder attached to the underwater package; transducer, coder, receiver and minicomputer aboard the ship.

Slant ranges are determined by measuring the round trip travel time of individual acoustic pulses between the ship and the transponders. Corrections are provided for ray bending, sound velocity variations, system delays and ship movement.

The system was developed for use with the three-man research submersible *Alvin* which recently participated in FAMOUS, an international research project in the Mid-Atlantic Ridge. The combination of standard bottom sampling equipment (dredges, samplers, cameras) with this system has provided a new dimension in sampling accuracy. A long-term survey camera has taken over 40,000 photographs which can be related precisely to the survey area.

The potential uses for the system are practically unlimited where accurate positioning is desired. The ability to work with any wire-lowered or free vehicle opens applications such as planting special bottom packages, or siting and installing offshore facilities.

Published in: *Proceedings of the IEEE OCEAN '75 (Institute of Electrical and Electronic Engineers) Conference, Halifax, Nova Scotia.*

Supported by: *Office of Naval Research Contract N00014-75-C-0681; NR 294-017.*

*NAVIGATION TRANSPONDER SURVEY: DESIGN AND ANALYSIS*

Woollcott Smith, William M. Marquet and Mary M. Hunt

Near-bottom moored transponders are being used for precision navigation in the deep ocean. To use these navigation systems the relative positions of the transponders must be determined. Typically, a ship surveys the transponders by making slant range measurements from a series of survey points; the positions of the transponders are then estimated, using standard nonlinear least square methods. In this paper we use some ideas from the design of nonlinear experiments to find survey patterns that can improve the estimates of the transponder positions. We will analyze the standard three transponder geometry. Our methods show that the accuracy of the least squares estimation procedure is very sensitive to the survey geometry. Careful design of the survey pattern can increase the accuracy of the survey by a factor of five to ten.

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Supported by: *Office of Naval Research Contract N00014-75-C-0681; NR 294-017.*

## PHYSICAL OCEANOGRAPHY

*ENHANCEMENT OF DIRECTIONAL WAVE SPECTRUM ESTIMATES*

Narayana N. Panicker and Leon E. Borgman

Determination of the directional distribution of ocean surface waves is of practical importance and analytical schemes for it are developed and discussed here. Based on a generalized representation of wave properties such as surface elevation, subsurface pressure or horizontal components of water particle velocity, acceleration or wave force, two general schemes of analysis are developed. In one scheme the predictive equations for the directional distribution of both the amplitude and phase of waves are derived. Distribution of energy as a function of direction for random waves is obtained in the other scheme. Fourier series parameterization is used to represent directional spectrum. The truncation of the series dictated by data limitations introduce directional spread and negative side lobes for the estimated directional spectrum. A procedure to remove these undesirable side lobes by a non-negative smoothing function is described. The smoothing causes further directional spread. Methods for obtaining better directional resolution are discussed. Data adaptive spectral analysis techniques such as Maximum Likelihood Method and Maximum Entropy Method are suggested.

Published in: *14th International Conference on Coastal Engineering: American Society of Civil Engineers, 1975.*

Supported by: *Office of Naval Research Contract N00014-74-C-0569; NR 083-004.*



*DEEP STEPPED STRUCTURE IN THE TYRRHENIAN SEA*

Robert Molcard and Albert J. Williams, 3rd

In May 1973 a joint experiment between the Woods Hole Oceanographic Institution and the SACLANT ASW Research Centre was mounted to study the deep stepped structure of the Tyrrhenian Sea. The variability of the structure in space and time was measured with a Bissett Berman STD. At several stations, the microstructure was measured with a special purpose probe which included an optical device for salt finger detection. Great horizontal continuity of the layers was confirmed. Salt fingers were observed at 1 meter steps within the 6 meter interfaces between 50 meter and 150 meter homogeneous layers. The fingers did not seem to be responsible for the stepped structure as they did not occupy the entire interface.

Published in: *Memoires Societe Royale des Sciences de Liege, 6<sup>e</sup> serie, VII, 1975.*

Supported by: *Office of Naval Research Contract N00014-66-C-0241; NR 083-004.*

## STATISTICS APPLIED TO OCEANOGRAPHY

*CLUSTERING OF VOLUME REVERBERATION SPECTRA:  
AN APPLICATION OF CORRESPONDENCE ANALYSIS*

Paul T. McElroy and Woollcott Smith

Correspondence analysis has been applied to 34 spectral curves of volume reverberation to cluster the spectra into groups. The clustering is compared with an earlier grouping of the spectra based on the cross-standard-deviation matrix with essentially similar results. However, the correspondence analysis technique has a number of clear-cut advantages: (1) the clustering is quickly displayed in a two-dimensional plot; (2) eigenvectors computed in the analysis are spectral curves which are characteristic of extremum environments in the data set (we call them volume reverberation environments and discuss their possible identification with preponderant fish species); (3) those frequencies which most directly serve as indicators of a particular cluster of spectra are identified; and (4) the examination of the relationship of environmental parameters and the factor scores computed in the analysis provide a basis for extrapolation of the spectra to their appearance in unmeasured conditions. The volume reverberation spectra (known as column strengths) are chosen as a particular example of the application of correspondence analysis; we believe it is broadly applicable to the problem of identifying and classifying spectra in many disciplines. As an aid to the reader in understanding the technique, we have summarized the governing equations of correspondence analysis and given a geometrical interpretation relating the original spectra, eigenvectors, and factor scores.

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*A SIMILARITY MEASURE SENSITIVE TO THE CONTRIBUTION OF RARE SPECIES  
AND ITS USE IN INVESTIGATION OF VARIATION IN MARINE BENTHIC COMMUNITIES*

J. Frederick Grassle and Woollcott Smith

We propose a new measure of similarity, the normalized expected species shared or NESS. The measure is based on the expected number of species shared between random samples of size,  $m$ , drawn from a population. The NESS measure is shown to be a generalization of Morisita's similarity and is demonstrated to be less biased than other commonly used measures. The contribution of dominant and rare species is explicit according to the sample size,  $m$ , chosen. For large  $m$ , NESS is sensitive to the less common species in the populations to be compared. To illustrate the usefulness of the NESS measure two quite different marine benthic examples are presented. In each case the presence or absence of the less common species is an important consideration. The spatial and temporal relationships of the benthic samples can be predicted from the cluster diagrams based on the NESS similarities.

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*SAMPLING PROPERTIES OF A FAMILY OF DIVERSITY MEASURES*

Woollcott Smith and J. Frederick Grassle

A generalization of Simpson's diversity index is defined as the expected number of species in a random sample of size  $m$ . This diversity measure is shown to have a minimum variance unbiased estimator, and the variance of this estimator can be obtained. Several examples are given, and the expected species index is compared with Shannon's information measure. Because of its well-defined statistical properties the expected species measure can be used to present clearly spatial and temporal variability in the diversity of natural communities.

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# PHYSICAL OCEANOGRAPHY

PO-1

DEPARTMENT OF PHYSICAL OCEANOGRAPHY

L. Valentine Worthington, Department Chairman

## OCEAN CIRCULATION AND WATER PROPERTIES.

## REVIEW OF THE PHYSICAL OCEANOGRAPHY OF GEORGES BANK

Dean F. Bumpus

Previously published information on the bathymetry, rotating tidal currents, temperature-salinity distribution and general circulation of the Gulf of Maine and Georges Bank are discussed. New information on surface temperature fronts in relation to monthly Ekman transport vectors is presented. Data on the distribution of herring larvae during successive periods during the autumns of 1972, 1973, and 1974 are used as evidence of dispersion and advection. Feasible approaches toward development of a circulation model are mentioned.

Supported by: *National Marine Fisheries Service Contract 03-5-043-327.*

## A THEORETICAL MODEL OF THE FLOW IN THE MOUTH OF SPENCER GULF, SOUTH AUSTRALIA

John A. T. Bye and John A. Whitehead, Jr.

The salinity distribution in Spencer Gulf, South Australia, indicates an inflow of low salinity water on the West side of the Gulf, modification of the water mass at the northern end and an outflow of water of increased salinity on the East side. This system appears to be an excellent example of a theoretical model recently proposed by Whitehead, Leetman & Knox (1974) for flushing controlled by a buoyancy-inertial current.

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STATISTICAL OBSERVATIONS OF THE TRAJECTORIES OF NEUTRALLY BUOYANT FLOATS  
IN THE NORTH ATLANTIC

Howard J. Freeland, Peter B. Rhines, H. Thomas Rossby

This is a report of the statistical behavior of neutrally buoyant SOFAR floats, drifting at 1500 m depth in the Sargasso Sea where the currents are dominantly time-dependent. The float level is fairly typical of the deep ocean below the main thermocline.

Westward propagation of streamline patterns was unambiguously present over a 180-day period, at an average speed of 5 cm/sec. This exceeded the r.m.s. particle speed (4 cm/sec) and far exceeded the mean westward flow ( $\approx 0.9$  cm/sec).

The spatial correlation functions are calculated, and show significant anisotropy of the spatial scales. This anisotropy may be related to the direction of the energy flux in the MODE area.

Maps of the time-averaged intensity and anisotropy of the currents show that, even after eighteen months, there remain strong spatial gradients of kinetic energy density on the 100 km scale: decreasing eastward, especially abruptly at the transition from a flat to a hilly sea-floor: and increasing both northward and southward

from the center of the experiment (28°N, 69°40'W).

The polarization of the time averaged currents was significant and quickly varying in space. Such striking 'fine-structure' in the eddy field suggests strong topographic control, both by the irregular shape of the nearby continental rise, and the variations of sea-bed roughness and slope. Even linear planetary waves can show this complex behavior if subjected to irregular ocean bottom and margins.

The Lagrangian auto-covariance function is calculated, and provides a measure of lateral diffusion by the energy-containing eddies, particularly relevant to the Mediterranean salt tongue which intersects this region. Nevertheless the detailed history of the floats is richer than implied by a simple diffusion.

The Lagrangian frequency spectrum has a first moment corresponding to a 51-day period, which may be taken as characteristic of the energy-containing eddies. The Eulerian frequency spectrum, from current meters, has a first moment corresponding to a 54-day period, similar to the Lagrangian value.

Other Eulerian-Lagrangian comparisons suggest agreement in measurements of the average energy density, differences in the shapes of the frequency spectra, and some uncertainty in the time and space-averaged currents. Long float-drifts are well-suited to measuring mean currents, except for a bias due to spatially varying eddy intensity, and a possible bias due to their imperfectly Lagrangian nature.

In all, three independent measures of the nonlinearity of the current field are given. The ratio of r.m.s. current speed to pattern propagation speed, 0.8, suggests marginally linear dynamics, as does the ratio of the Eulerian to Lagrangian time scales, 1.0. The ease with which mixing of fluid particles occurs, fully comparable to random walks of the same time and velocity scales, indicates a rather stronger level of nonlinearity.

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*THE INTERACTION OF ZONAL CURRENTS WITH TOPOGRAPHY;  
WITH APPLICATIONS TO THE SOUTHERN OCEAN*

Michael S. McCartney

An analytical model is developed for the interaction of a broad, eastward directed, baroclinic current with shallow bottom topographic features in an unbounded  $\beta$ -plane ocean. Solutions are presented for three types of topography: a meridionally oriented ridge such as is found in the central South Pacific and South Atlantic sectors of the Southern Ocean, a zonally oriented ridge such as is found south of Australia and Africa, and an isolated plateau or seamount. The meridional ridge is found to cause a stationary wave pattern similar to that believed to occur in the southeast Pacific Ocean. The zonal ridge is found to cause a current intensification on the equatorward side of the ridge crest, with intermittent slowed or reversed flow and a string of stationary warm core eddies on the poleward side. Comparison is made to Callahan's (1971) observations of the flow along the ridge south of Australia. The isolated seamount forces a Taylor column (warm core anticyclonic eddy) above it, and has a stationary meandering wake downstream, sometimes with embedded cyclonic and anticyclonic eddies.

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*SOME EFFECTS OF LATERAL SHIFTS OF THE GULF STREAM ON THE CIRCULATION  
NORTHEAST OF CAPE HATTERAS*

Charles E. Parker

An analysis of data obtained from the U. S. Coast Guard Environmental Buoy EBO-1 for the period of August, 1971 to June, 1972 is presented. The buoy located off the Virginia Capes at approximately  $36^{\circ}30'N$  and  $73^{\circ}30'W$  was programmed to provide hourly meteorological and oceanographic data to a shore station via a radio link. Identification of water types present at the buoy during the measurement period has been made through the comparison of the transmitted data with special monthly temperature/salinity diagrams. Monthly progressive vector diagrams of velocity for each water type are also presented. Correlations between the lateral shifts in the Gulf Stream position and the offshore *relative volume transport* of various water types are discussed.

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*ON THE CROSSOVER BETWEEN GULF STREAM AND WESTERN BOUNDARY UNDERCURRENT*

Philip L. Richardson

To determine how the Gulf Stream and Western Boundary Undercurrent cross each other near Cape Hatteras, six current meters were moored during May-July 1971 along a line normal to the Gulf Stream axis and 100 m above the ocean floor in depths from 1200-4200 m. Peak velocities of the six records (including one of 47 cm/sec) and the mean velocities of four of the deepest records (2800 to 4000 m) were in the southwest quadrant. During the period of observations the Gulf Stream did not extend to the bottom of this area except in brief current reversals to the northeast. The Western Boundary Undercurrent flowed southwest under the Gulf Stream parallel to the bottom contours. The transport of the Undercurrent, estimated using two geostrophic velocity sections and deep current meter observations, was  $24 \times 10^6 \text{ m}^3/\text{sec}$ .

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*CONVERSION OF PRESSURE TO DEPTH IN THE OCEAN*

Peter M. Saunders and Nicholas P. Fofonoff

Employing the Knudsen-Ekman formulation for specific anomaly a five-term expression is found relating depth and pressure in the ocean. The first four terms provide the conversion in a standard ocean and the remaining term is proportional to the dynamic height anomaly in the water column. In the conversion the importance of the variation of gravity both with latitude and depth is illustrated.

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*PERTURBATIONS TO THE GULF STREAM BY ATLANTIS II SEAMOUNT*

Andrew C. Vastano and Bruce A. Warren

In a search for a natural occurrence of Taylor-column effects, a set of STD (Salinity, Temperature, Depth) stations was occupied in the Gulf Stream as it passed over Atlantis II Seamount. Although the Stream path changed markedly during the course of the observations, one five-day subset of stations seems to provide a quasi-synoptic picture of the flow. Maps, based on this subset, of potential temperature at eight levels between 200 m and 3500 m show deflections and distortions of isotherms in the vicinity of the seamount, and warm-core and cold-core eddies in its lee. The eddies are probably a consequence of the recent incursion of the Stream onto the seamount, while the other features seem qualitatively intelligible in terms of existing Taylor-column theory. From the data available, however, it is not possible to tell with certainty whether there existed any region of closed streamlines just above the seamount.

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*NOTE ON INTERPRETING e-FOLDING DEPTHS*

Bruce A. Warren

Exponentials are often fitted to observed distributions of conservative properties vs. depth in the deep ocean in order to estimate ratios of vertical diffusion coefficient to vertical velocity from the derived e-folding depths. This technique rests on an assumed balance between vertical advection and vertical diffusion of the property in question, and can give misleading results if lateral mixing is important in the property balance. Two illustrative examples are given: one, of horizontal variation in the e-folding depth despite a constant value for the above ratio, and the other, of a uniform value for the e-folding depth despite large horizontal variation in the ratio.

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*THE LIMITS OF SHELF WATER SOUTH OF CAPE COD, 1941 TO 1972*

W. Redwood Wright

Some 19,000 bathythermograms and 1,600 oceanographic stations in the region  $39^{\circ}$  to  $41^{\circ}$ N,  $69^{\circ}$  to  $72^{\circ}$ W have been examined for evidence of changes in the character and position of the Shelf Water/Slope Water boundary. Results show a) the boundary, identified by the  $10^{\circ}$  isotherm, intersects the bottom within 16 km of the 100-m curve about 80 percent of the time, with a seasonal progression from the south in the winter to north in the fall; b) at the sea surface the boundary position is much more variable, averaging 52 km seaward of the 100-m curve in winter and 72 km seaward in late summer; c) detached parcels of Shelf Water are found in the Slope Water at all times of the year, with maximum occurrence in late spring and early summer; and d) the combination of entrainment at Hatteras and production of detached parcels appears to account for the Shelf Water/Slope Water exchange required by salt balance considerations.



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*A VOLUMETRIC TEMPERATURE/SALINITY CENSUS FOR THE MIDDLE ATLANTIC BIGHT*

W. Redwood Wright and Charles E. Parker

Two seasonal volumetric temperature/salinity diagrams have been prepared for the waters of the Middle Atlantic Bight from Nantucket Shoals to Cape Hatteras, to a depth of 200 m and extending as much as 130 km beyond the edge of the continental shelf. Total volume included is 23,145.6 km<sup>3</sup>, of which about half is Slope Water, more saline than 35<sup>0</sup>/∞. Most of it is in a distinctive subsurface maximum region near 13°C, which is named the Upper Slope Water Thermocline. The less saline Shelf Water has two modes divided by a minimum near 33.6<sup>0</sup>/∞. The fresher mode, associated with shallow depths, is identified as Coastal Water; that from 33.6<sup>0</sup>/∞ to 35<sup>0</sup>/∞ is called Shelf Edge Water, and much of it is found seaward of shelf break. There is very little seasonal change in the total volume of Shelf Water but its geographical distribution varies, showing the effects of spring runoff and suggesting a summer influx of Slope Water in the northern portion of the Bight. Comparison with a similar census for the Gulf of Maine and shelf waters to the east shows some overlap but little evidence of substantial exchange.

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*ON THE MEDITERRANEAN OUTFLOW WEST OF GIBRALTAR*

Walter Zenk

During "Meteor" cruise 23 in spring 1971 intensive investigations of the Mediterranean outflow in the Gulf of Cádiz were carried out. In order to give a budget of the inflow and outflow numerous CTD-stations were taken. The observations also included six moored current meter arrays deployed in the known outflow channels. The considerations given here are based mainly on three hydrographic sections, current meter records averaged over one month, and geological observations from the bed forms beneath the Mediterranean undercurrent. The results show that the outflow essentially is determined by the bathymetry of the area. At least four separate outflow channels could be confirmed. The volumetric transport rates of three of them were calculated. These channels are the northerly near shelf branch ( $0.40 \cdot 10^6 \text{m}^3 \text{sec}^{-1}$ ), the main branch ( $1.39 \cdot 10^6 \text{m}^3 \text{sec}^{-1}$ ) in southwesterly direction, and an intermediate branch ( $0.24 \cdot 10^6 \text{m}^3 \text{sec}^{-1}$ ) found between both. In a static box model the progressive mixing of  $0.95 \cdot 10^6 \text{m}^3 \text{sec}^{-1}$  pure Mediterranean Water with  $1.97 \cdot 10^6 \text{m}^3 \text{sec}^{-1}$  North Atlantic Central Water is demonstrated.

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## SURFACE LAYER PROCESSES AND METEOROLOGY

*CIRCULATION, DIFFUSION AND FRONTAL DYNAMICS IN THE COASTAL ZONE*

Gabriel T. Csanady

A status report on coastal boundary layer research in the Great Lakes is given. The "first order" or longshore flow is now understood in terms of the conceptual models of coastal jets, Kelvin waves and topographic waves. Secondary flow perpendicular to shore ("cross-flow" for short) is less well understood, although its understanding is crucial for a parametrization of the mass exchange between coastal zone and midlake. Various contributions to cross-flow are discussed and their importance in the mass exchange process estimated.

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*ASYMPTOTIC REGIMES IN MIXED-LAYER DEEPENING*

Roland A. de Szoeke and Peter B. Rhines

The model equation for the mixed layer proposed by Niiler combines the Kraus-Turner turbulent erosion prescription with the Pollard-Rhines-Thompson treatment of induced shear-flow deepening and limiting by Coriolis forces. We show here that both are special cases which emerge asymptotically from the model equation. Numerical solutions show the dynamics to pass through four distinct regimes, in the case of wind-mixing of an initially resting fluid.

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*THE SCALING OF VELOCITY FLUCTUATIONS IN THE OCEAN MIXED LAYER*

Ian S. F. Jones and Bernard C. Kenney

Turbulent velocity fluctuations in the upper portions of the wind-driven mixed layers of oceans or lakes appear to scale on the surface shear stress and the distance from the free surface. A number of velocity spectra have been measured in marine mixed layers and the scaled spectra compared with turbulent boundary layer measurements. The good agreement suggests that the surface wave orbital velocities act merely as "inactive" motions and do not interfere with the lower frequency stress carrying eddies.

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*THE SIGNIFICANCE OF THE MEDITERRANEAN SEA TO GLOBAL CLIMATOLOGY*

Arthur R. Miller

Food production is affected by climate and by climate change. The indices for climate change may be recognized in long-term systematic observations of oceanic water columns at selected referential sites. The Mediterranean Sea, as part of the global oceanic circulation system, may be sensitive to climatic variation and may have an influence upon climate. The establishment of international reference stations for the Mediterranean area is suggested.

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*ON THE UNCERTAINTY OF WIND STRESS CURL CALCULATIONS*

Peter M. Saunders

In a  $10^{\circ}$  square test area of the North Atlantic the annual wind stress is estimated in  $1^{\circ}$  squares from volunteer ship reports. The curl of the wind stress is deduced therefrom and is shown significantly different from that recently published based on the  $5^{\circ}$  square wind stress data of Hellerman. The coarse resolution of the latter underestimates maxima and minima in the curl by up to 50%. Two 'acceptable' forms of the wind stress law are examined and shown also to change wind stress curl magnitude by 50%. The need for further marine micrometeorological research is emphasized as well as the need for amassing all available shipping information in order to reduce these uncertainties.

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*CLIMATOLOGICAL NUMERIC MODELS OF THE SURFACE MIXED LAYER OF THE OCEAN*

Rory Thompson

The slab model (PRT) of the surface mixed layer of the ocean proposed by Pollard, Rhines and Thompson is given a simple and fast computer implementation. Actual meteorological data from Ocean Weather Station "N" is used for a year-long forecast. The results compare quite well with the observations of vertical temperature profiles, with a correlation of 0.98 between predicted and observed sea-surface temperatures and of 0.8 between predicted and observed mixed-layer depths. Temperature anomalies introduced in the Spring can be covered up in the Summer, yet reappear in the Winter. A constant thickness slab is also suitable as a lower boundary for some atmosphere climatological studies, if a depth of 25 metres is used. The model of Denman, Kraus, and Turner is also implemented and does well, but PRT seems to be somewhat better for climatology studies.

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# WAVE DYNAMICS

## SURFACE, INTERNAL, ROSSBY WAVES

PRELIMINARY RESULTS FROM THE TRI-MOORED INTERNAL WAVE EXPERIMENT (IWEX)

Melbourne G. Briscoe

A three-dimensional array of 20 current meters, temperature sensors, and vertical temperature-gradient sensors was successfully deployed for 40 days in late 1973 in the main thermocline over the Hatteras Abyssal Plain southeast of Bermuda. Sensor spacings in the main array were 1.4 to 1600 m in the horizontal, 2.1 to 1447 m in the vertical. The minimum sampling interval was 225 seconds.

The ultimate purpose of the experiment was to estimate a vector wave number-frequency spectrum of internal waves without the usual assumptions of simple modal structure, horizontal isotropy, and linearity.

Auto-spectra from the array normalize quite well in depth according to the WKBJ "high-mode" solutions. Spectra of vertical displacements show a significant contribution from the internal semi-diurnal tide.

Samples of 1760 cross-spectra calculated (based on a 40-day averaging interval) suggest horizontal isotropy, vertical homogeneity, and a possible degradation of current coherences because of fine structure in the horizontal velocity profile.

Coherence of vertical displacements (i.e., temperature fluctuations) for measurements separated horizontally decays with increasing separation according to  $f_{1/2}X = 330 \text{ m} \cdot \text{cph}$ , where  $f_{1/2}$  (cph) is the frequency at which the coherence falls to one-half, and  $X$  (m) is the horizontal separation. This empirical rule is based on  $1600 \text{ m} > X > 140 \text{ m}$ ; for smaller  $X$ ,  $f_{1/2}$  exceeds the local buoyancy frequency.

Auto- and cross-spectra of vertical displacements sometimes show peaks at frequencies just less than the local buoyancy frequency; current spectra do not show such peaks.

Inverse modelling of the internal wave field is in progress; expected results are a vector wave number-frequency spectrum, and a description in parameter space that hopefully will permit future experiments to be less elaborate.

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### TOPOGRAPHIC WAVES IN LAKE ONTARIO

Geoffrey T. Csanady

Properties of a topographic wave are calculated for an idealized shore zone model simulating the north shore of Lake Ontario. Observations at the Oshawa "coastal chain" taken during the International Field Year on the Great Lakes are then scrutinized, concentrating on three flow-reversal episodes involving deep, barotropic currents. It is shown that the observed phenomena have characteristics very similar to those of the idealized topographic wave. A legitimate interpretation of the observed 12-16 day periodicities in longshore flow within the coastal

zone of Lake Ontario is that they are caused by a combination of internal Kelvin waves and topographic waves. Although the speeds of these two kinds of vorticity waves are very similar in Lake Ontario, a careful consideration of the evidence clearly shows phase separation, particularly so late in the season when reduced density differences lead to a slowing down of internal Kelvin waves.

Supported by: *Great Lakes Environmental Research Laboratory, National Oceanic and Atmospheric Administration Contract 03-5-022-26.*

#### OBSERVED INTERACTION BETWEEN OCEANIC INTERNAL WAVES AND MESOSCALE EDDIES

Claude Frankignoul

Measurements from arrays of moored current meters taken during the Mid-Ocean Dynamics Experiment (MODE) are analyzed, using short-term spectral analysis. A weak variability in space and time is detected in the internal wave continuum, as well as some horizontal anisotropy. It is suggested that the observed anisotropy is induced by the weak interaction between the internal wave field and the eddy field, in agreement with the theory of Müller (1974). The relaxation time of the internal wave continuum is found to be of the order of two to three days in the vicinity of the main thermocline, which agrees in order of magnitude with the value computed by Olbers (1974) for the characteristic time of the nonlinear energy transfer within the spectrum. From observed correspondences between the fluctuations in total internal wave energy and mean vertical shear, a preliminary estimation of the vertical eddy viscosity induced by internal waves is attempted, suggesting that  $\nu_v$  is  $\sim 0$  ( $10^3 \text{ cm}^2/\text{s}$ ) for the main thermocline.

Supported by: *Applied Physics Laboratory of The Johns Hopkins University Contract 372111; and National Science Foundation Grant GX-29033 (Harvard, A. Robinson).*

#### QUASIGEOSTROPHIC LEE WAVES - THEORY AND OBSERVATION

Nelson G. Hogg

We examine three situations in which lee waves will be forced by isolated topography in a slowly moving, stratified rotating fluid. These quasigeostrophic waves require an agency for vortex line compression for their existence. In two cases studied, where either the fluid bottom slopes or the upstream flow has shear (or both), this compression occurs through transverse motions at the boundary working against the pinching together of the isopycnal and boundary: maximum amplitudes occur at the boundary. In the third case, the upstream flow has curvature and the geostrophically balanced isopycnals have slopes dependent on depth which can support a wavelike motion whose maximum is in the interior. These cases are studied in some detail and properties such as wavenumber and forced amplitude are computed as functions of upstream shear, stratification, and bottom slope.

We also present an interpretation of some observations taken near a small seamount during MODE-I in terms of this mechanism. The existence of a deep strong flow in velocity profiles and neutrally buoyant float tracks and small horizontal scales supports the suggestion that a quasigeostrophic lee wave of the third type is being forced by interaction of the MODE-1 eddy with the seamount.

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## ON A DIAGNOSTIC CONCEPT TO TEST THE INTERNAL WAVE STRUCTURE

Peter Müller and Gerold Siedler

A complete set of linearly independent relationships among the different cross-spectral components obtained from pairs of moored instruments is derived which can be utilized to test whether or not the observed fluctuations within the internal wave frequency band represent a field of propagating internal waves. A further complete set of relationships is derived which enables to test whether or not the internal wave field is horizontally isotropic and (or) vertically symmetric. These relations are compared with corresponding relations for alternative models (isotropic turbulence, standing internal wave modes) and their capability to discriminate between the various models is investigated. The tests are applied to a set of data for which it is found that the observed fluctuations are consistent with both propagating and standing internal waves whereas isotropic turbulence must be rejected for the most part of the internal wave frequency band.

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## THE DYNAMICS OF UNSTEADY CURRENTS

Peter B. Rhines

This is an account of the physics of oceanic eddies and waves. A historical review, §I, is followed by a description of kinematics, §II, which illustrates the visual difference between patterns of pressure, velocity, vorticity, and density, and uses them to make dynamical tests on the basis of records from single moorings.

§III describes the dynamics of an ocean that is driven extremely gently, involving Sverdrup flow and long, baroclinic waves. §IV treats currents that result when the ocean is driven by forces that are weak, yet vary more quickly in time. These 'eddies' are topographic Rossby waves, which carry time-dependent energy about the ocean. Observations of the three principle wave modes are given, particularly the recently-verified property of westward phase propagation.

§V gives the theory and computer simulation of nonlinear cascades in a flat-bottomed ocean. These occur when the ocean is driven more vigorously than above. It is found, typically, that significant interactions occur among eddies that modify their structure, before propagation has moved their energy a single wavelength. The cascades carry barotropic (depth-averaged) energy to large length-scale. But wave effects can halt this lateral expansion of eddies, and turn turbulence into waves. Baroclinic energy (currents with vertical shear) moves toward the Rossby deformation scale from either smaller or larger scales. Then eddies in the deep and in the shallow water lock together, producing a barotropic state. A proof of this cascade is given. This ability of the fluid to switch modes means that energy propagation across the sea will be much faster for the more energetic eddy fields.

§VI adds the crucial effect of a rough ocean bottom to this story. It is found that eddies achieve a 'comfortable' structure which depends on the roughness of the bottom.

§VII is a theory of the generation of ocean circulation by eddies. It leads to simple relations between the ability of eddies to 'stir' the ocean, and their ability to induce a time-averaged flow. In much of the ocean these new circulations should swamp the classical, wind-driven flow.

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*RESONANT INTERACTIONS AMONG BAROCLINIC INERTIO-GRAVITY AND ROSSBY WAVES*

Barry R. Ruddick

Weak resonant nonlinear triad interactions are investigated for a rotating baroclinic system. It is found that when one member of the triad is a Rossby wave, it has the role of a catalyst, not changing in amplitude or phase itself, but enabling the two internal-inertial waves to interact. However, for a triad consisting of one inertial oscillation and two internal-inertial waves, numerical evaluation of the exchange coefficients indicates that the inertial oscillation does take an active part in the interaction.

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*OBSERVATIONS OF THE VERTICAL STRUCTURE OF INTERNAL WAVES*

Thomas B. Sanford

Velocity profiles in the open ocean reveal variations in the current structure throughout the water column. Superimposed on a smooth low-frequency shear profile are many layers of large time-variable shear. Repeated profiles at one location show that the time-dependent structure is dominated by rotary currents of diurnal-inertial period. Coherence calculated between profiles lagged in time indicates downward energy propagation. The kinetic energy of these internal waves varies with depth in a manner similar to that of the Brunt-Väisälä frequency, but over a brief series of profiles there can be localized zones which are more energetic than might be expected. Based on velocity shear measured over 10-dbar intervals and a time mean Brunt-Väisälä profile, Richardson numbers between  $\frac{1}{2}$  and 4 are observed over much of the water column. Simultaneous profiles are most similar at a separation of 100 m, gradually becoming more different for larger separations of up to 10 km.

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*ROSSBY WAVES NEAR SITE D - OBSERVATIONS OF TEMPORAL STRUCTURE*

Rory O.R.Y. Thompson

On the slope north of the Gulf Stream, theory predicts potential-vorticity conserving motions for periods of a week to a month or more. An array of current meters was put out near Site D (39°10'N, 70°W) to test the predictions of the theory. Wave numbers were estimated for periods of 32, 16, 11, and 8 days, and found to be similar for 4 eight-month records at each of two depths (1000m and 2000m). Most of the wave numbers point to the southwest quadrant, consistent with eastward propagation and with momentum flux into the Gulf Stream. There is enough consistency between statistics based on successive eight-month records to conclude that statistics based on a single eight-month record near Site D are meaningful.

Supported by: *Office of Naval Research Contracts N00014-66-C-0241, NR 083-004 and N00014-74-C-0262, NF 083-004.*

## MICROSTRUCTURE, FINE STRUCTURE, ETC.

### *LARGE SCALE VARIATIONS IN SMALL SCALE TEMPERATURE/SALINITY FINESTRUCTURE IN THE MAIN THERMOCLINE OF THE NORTHWEST ATLANTIC*

Terrence M. Joyce

Large scale variations of temperature/salinity finestructure have been observed in the main thermocline of the northwest Atlantic Ocean on an oceanographic section along 70°W from the Sargasso Sea to the continental slope. Results suggest that temperature/salinity variability associated with oceanic mixing increases linearly northward as the continental slope and the Gulf Stream are approached from the Sargasso Sea in the south.

Supported by: *Office of Naval Research Contract N00014-74-C-0262, NR 083-004.*

### *DISCRIMINATION BETWEEN INTERNAL WAVES AND TEMPERATURE FINESTRUCTURE*

Terrence M. Joyce and Yves Desaubies

Discrimination between internal waves and finestructure in the ocean is made difficult because of overlapping scales of each process. We have assumed as a working hypothesis that low frequency/wavenumber variability is predominantly wavelike while high frequency/wavenumber variability is steplike. Thermal finestructure is modelled as a steppy Poisson process in the vertical while internal waves are modelled as a random Gaussian process. The model developed is an extension of one of McKean (1974). We describe the vertical temperature spectrum of finestructure and moored temperature and temperature difference measurements of IWEX. For the data considered, the contamination of moored/dropped spectra and cross-spectra is small for low frequencies/wavenumbers. The vertical temperature difference, measured over a vertical distance which is small compared to the correlation length of the internal wave field, is shown to provide a critical check of the model, since this signal is directly related to finestructure variability. Thus, it appears possible to use moored differential temperature sensors as monitors of finestructure activity.

Supported by: *Applied Physics Laboratory of The Johns Hopkins University Contract 372111 and Office of Naval Research Contract N00014-74-C-0262, NR 083-004.*



A QUASI-LAGRANGIAN STUDY OF MID-OCEAN VARIABILITY  
USING LONG RANGE SOFAR FLOATS

H. Thomas Rossby, Arthur D. Voorhis and Douglas C. Webb

Twenty neutrally buoyant SOFAR floats were used in the Mid-Ocean Dynamics Experiment (MODE) to study the structure and variability of the deep ocean currents. The floats were clustered so that the pattern of motions could be resolved (mapping and pattern recognition). A number of float trajectories are shown and the very individual character of their signature is emphasized. Some floats remain nearly stationary for a year whereas others will cover hundreds of kilometers to the south or west in just a few months. Superposition of all trajectories in the spaghetti diagram is shown to reveal considerable organization of the "eddy" field in the MODE area and is thought to be caused by the near presence of the Blake-Bahama Outer Ridge to the west. There is considerable asymmetry to the float dispersal with floats rapidly scattering to the south and west, but not to the north and east even though the r.m.s. velocities are a factor three to six times greater than the mean drift.

The evolution and dispersal of the float cluster is illustrated in a set of figures in each of which a 12-day segment of all float trajectories is displayed. At times their mobility and relative motion is shown to be associated with onset of sudden swirls and regions of large horizontal shear, features that are not evident from the analysis of individual trajectories.

Cluster averages of the float velocities and kinetic energy, computed weekly and plotted as a function of time, show substantial variability.

Much better averages are obtained by limiting the cluster to floats within a geographical region. As the spaghetti diagram indicates and the following paper discusses in more detail, there exist substantial geographical variations in the average kinetic energy levels. These may be in some way caused topographically by the close proximity to the continental margin. Whatever the reason they caution us to reexamine the notion that the scale of variation of the second order eddy statistics is large compared to the eddies themselves, at least in the MODE-I area.

Ten floats also contained a system to record the local pressure, temperature and vertical currents. The pressure and temperature yield data concerning low frequency vertical displacements and the vertical current meters measure the internal wave sea state which is shown to be remarkably constant.

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*Office of Naval Research Contracts: N00014-66-C-0241, NR 083-004 (WHOI),*  
*N00014-67-A-0097-001 (Yale).*

ON THE ORIGIN OF THE INTERMEDIATE DOUBLE-MAXIMA IN T/S PROFILES

Walter Zenk

Continuous temperature and salinity profiles from the NE-Atlantic frequently show a double-maxima structure within the depth range of the Mediterranean outflow. Two explanations for this special thermohaline stratification can be found in literature: a) The density of the outflow is varied by different outflow channels with unequal mixing properties. b) In the Strait of Gibraltar two different outflowing

water types are produced by tidal currents. In both cases the different water masses spread in different density levels in the Atlantic.

Data presented here indicate that the bimodal structure must be caused primarily by tidal currents at the source. Two-layered outflowing Mediterranean water was observed even before a splitting of the undercurrent in the Gulf of Cadiz takes place. The variability of the double-maxima can be explained by varying outflow rates in the source region rather than by a steady influence of the bottom topography.

Published in: *Meteor Forsch.-Ergebnisse*, No. 16. 1975.

Supported by: *Deutsche Forschungsgemeinschaft, Bonn-Bad Godesberg*.

## OTHERS

### *THE BEHAVIOR OF A BAROTROPIC EDDY ON A $\beta$ -PLANE*

Eric Firing and Robert C. Beardsley

An experimental method for producing an isolated eddy in a laboratory tank is described, together with the simple viscous theory of the behavior of the eddy in an ordinary cylindrical tank without  $\beta$ -effect. The linear inviscid theory incorporating the  $\beta$ -effect is then developed as an initial value problem, and the solution is found as a summation of normal Rossby wave modes of the basin. This theoretical solution is compared with results from laboratory experiments and with numerical simulations obtained for the "sliced-cylinder" laboratory model. It is found that nonlinear effects lead to a cyclonic circulation in the southern half. Two simple models are developed to account for these induced circulations.

Supported by: *National Science Foundation Grant GA 41073 and Hertz Foundation Fellowship*.

### *HYDRAULIC CONTROL BY A WIDE WEIR IN A ROTATING FLUID*

Edmund Sambuco and John A. Whitehead, Jr.

Flow control by a wide, deep weir in a rotating fluid is investigated theoretically and experimentally. The strong (vertical) vorticity constraint due to frame rotation is combined with conservation of the Bernoulli function along streamlines and a standard hydraulic control assumption to show that the volume flux over the barrier is

$$Q = g^{-1} \left[ \frac{2}{3} g(H-b_0) - \frac{1}{3} f^2 \ell^2 \right]^{\frac{3}{2}},$$

where  $H$  is the depth of the fluid column upstream,  $b_0$  is the crest height,  $f$  is the Coriolis parameter, and  $\ell$  is a length scale measure of the breadth of the weir. The component of the velocity parallel to the weir crest is computed from conservation of potential vorticity to be  $v = -f\ell$ ; perpendicular to the crest, we recover the standard hydraulic relation

$$u = g^{\frac{1}{2}} (H - b_0)^{\frac{1}{2}}$$

Experimental investigations of upstream height and streamline deflexion as functions of rotation are described. It is found that agreement with theory is good up to a certain rate of rotation, above which the finite width of the experimental weir becomes important

Supported by: *National Science Foundation Grant DES 72-01562.*

*CONVECTION MODELS: LABORATORY VERSUS MANTLE*

John A. Whitehead, Jr.

A general comparison is made between some laboratory convection experiments and behavior which the mantle appears to possess. The convection structure of a uniform viscosity fluid heated evenly from below is reviewed, and is seen to exhibit pronounced three-dimensionality at Rayleigh numbers which are believed to apply to the mantle. Some features which resemble tectonic features are described, but the convection is generally much more complex than simple two-dimensional motion. It is advocated that a new class of problems must be addressed involving surface plate-interior convection interaction. A theoretical stability analysis along these lines is described where each convection cell pushes a rigid plate at the upper surface. Under suitable conditions cells with a large width-to-depth ratio are predicted to be the most expected form. A second class of experiments and theory is described which is aimed at the problem of a movable energy source. Under some circumstances the convection in this case goes unstable to a drift which is of the same magnitude as the overturning time of the convection.

Supported by: *National Science Foundation Grant DES 72-01562.*

*THE PROPAGATION OF DISLOCATIONS IN RAYLEIGH-BÉNARD ROLLS AND BIMODAL FLOW*

John A. Whitehead, Jr.

When Rayleigh-Bénard convection is generated under random conditions, the finite amplitude rolls and bimodal flow are observed to possess randomly-placed dislocations where the rolls fit together poorly. The dislocations move, and it is observed that the dimensionless speed decreases as Prandtl number is increased.

Supported by: *National Science Foundation Grants GA-19605 and GA-35447.*

*OBSERVATIONS OF HIGH PRANDTL NUMBER CONVECTION  
AT RAYLEIGH NUMBERS UP TO 800,000*

John A. Whitehead, Jr. and Barry E. Parsons

Observations are reported of the stability and structure of Rayleigh-Bénard convection in fluid with a Prandtl number of 8,600, and a Rayleigh number between 50,000 and 800,000. Under carefully initiated and controlled conditions, stationary bimodal convection was observed. Under less carefully controlled conditions, oscillating spoke-shaped convection was observed.

Supported by: *National Science Foundation Grant DES 72-01562.*

## TECHNICAL REPORTS

### *ENERGY EXCHANGE AT THE SURFACE OF THE WESTERN NORTH ATLANTIC OCEAN*

Andrew F. Bunker

To supplement hydrographic studies of changes in the heat content of water masses, the energy fluxes through the ocean's surface have been estimated. These estimates have been computed from several million surface marine observations utilizing bulk aerodynamic exchange equations. The dependence of the transfer coefficients on wind speed and stability of the air was determined from the literature and used with the ships' data in the equations. The fluxes also have been computed following Budyko's method to serve as a check and comparison. The computations yield the monthly and annual fluxes of latent heat, sensible heat, momentum, and radiational exchange as well as averages of meteorological and oceanographical parameters. Monthly and annual charts of the net heat loss or gain by the ocean have been constructed for 150 areas which extend from the east coast to 30°W and from 20°N to 50°N. Charts of the latent heat, sensible heat, and radiational fluxes also are presented. Time series of the fluxes in different areas have been drafted. Several features revealed by the charts are analyzed and discussed.

Prepared for: *Office of Naval Research under Contract N00014-74-C-0262, NR 083-004.*

### *MOORING OPERATIONS OF THE WOODS HOLE BUOY GROUP FOR THE MID-OCEAN DYNAMICS EXPERIMENT*

Robert H. Heinmiller, Jr.

The Moored Array Project (Buoy Group) at the Woods Hole Oceanographic Institution carried out a series of moored-array experiments to measure currents and temperatures as part of the Mid-Ocean Dynamics Experiment (MODE). During the period from October, 1971 to August, 1974, a total of 44 moorings were deployed. This report summarizes the design, preparation, and field operations involved in the deployment and recovery of these arrays. Tabulations are included of all moorings set.

Prepared for: *Office of Naval Research under Contract N00014-74-C-0262; NR 083-004 and National Science Foundation Grant GX-29054.*

### *GAUSSIANTY OF THE CURRENT AND TEMPERATURE DATA FROM THE TRIMOORED INTERNAL WAVE EXPERIMENT (IWEX)*

Lucio Iida and Melbourne G. Briscoe

This report describes the time variability of the Gaussianity of the East and North velocity components, and the Up (vertical displacement) variable of the Internal Wave Experiment (IWEX). In order to use the classical Chi-Square and Two-Tailed

Kolmogorov-Smirnov goodness-of-fit tests on a Gaussian distribution, one must consider the correlation structure of the data, i.e., the non-white spectral characteristics of the three variables. Starting with artificially generated Gaussian random time series that are white in frequency space, the *Gentleman and Sande* (1966) method is used to incorporate desired spectral shapes into the series. Three frequency filters modeling the internal wave power spectrum very roughly and to different degrees of accuracy are used in the simulations. These in turn are used to find for the two goodness-of-fit tests new confidence levels that recognize the presence of an internal wave-like correlation structure in the data series. Finally, the evolution of the Gaussianity of East, North, and Up throughout IWEX is briefly discussed in this light.

No considerations were given to the frequency-domain behavior of the data, other than the overall spectral shape for use in generating the artificial data. In this sense, then, this report is a preliminary study only, because the temporal evolution of the Gaussianity of the various frequency bands in the internal wave field is the underlying question of importance to the study of internal wave self and external interactions.

Prepared for: *Office of Naval Research under Contract N00014-76-C-0197; NR 083-004 and Applied Physics Laboratory/Johns Hopkins University Subcontract 372115.*

#### VECTOR AVERAGING CURRENT METER SPEED CALIBRATION AND RECORDING TECHNIQUE

James R. McCullough

Equations 1-4 summarize the rotor calibration used at the Woods Hole Oceanographic Institution for the Vector Averaging Current Meter (VACM). A discussion of the instrumental and test details used to derive these equations follows. A list of other VACM documents and related bibliography is included.

Prepared for: *Office of Naval Research under Contracts N00014-66-C-0241; NR 083-004 and N00014-74-C-0262; NR 083-004; and International Decade of Ocean Exploration/National Science Foundation (IDOE/NSF) Grant GX-29054.*

#### A COMPILATION OF MOORED CURRENT METER AND WIND OBSERVATIONS, VOLUME VIII (1970 ARRAY EXPERIMENT)

Raymond T. Pollard and Susan A. Tarbell

Summaries of wind and current measurements made with current meters and wind recorders by the Woods Hole Oceanographic Institution during June, July and August of 1970 are presented.

Averaged quantities are presented in computer-generated output as basic statistics, spectra, demodulation plots, progressive vector diagrams, and east-north component plots.

Prepared for: *Office of Naval Research under Contract N00014-66-C-0241; NR 083-004.*

*A COMPILATION OF MOORED CURRENT DATA AND ASSOCIATED OCEANOGRAPHIC OBSERVATIONS, VOLUME IX. (1973 INTERNAL WAVE EXPERIMENT (IWEX))*

Susan A. Tarbell, Melbourne G. Briscoe, and Dolores H. Chausse

Summaries of basic current, temperature and pressure measurements made with instruments suspended from a subsurface tri-mooring by the Woods Hole Oceanographic Institution during the Internal Wave Experiment (IWEX) are presented. Also presented are data collected by a wind recorder during IWEX.

Average currents are presented in computer-generated output as basic statistics, histogram plots, spectra, progressive vector diagrams, east vs. north component plots, and variable vs. time plots.

Average temperature and differential temperature from the current meters are presented as basic statistics, histogram plots, spectra, and variable vs. time plots.

Pressure and temperature measurements from T/P recorders are displayed versus time.

Prepared for: *Office of Naval Research under Contract N00014-76-C-0197; NR 083-004 and for the Applied Physics Laboratory of The Johns Hopkins University under subcontracts 372111 and 372115.*

*CRUISE REPORT - KNORR 44*

George H. Tupper

*KNORR-44* was a single leg cruise, Woods Hole to Woods Hole. Duration of the cruise was 15 days, December 4-19, 1974. Fifteen deep-sea subsurface moorings were recovered, one of which was at sea for one year. The remaining moorings had been out for eight months. An east-west Gulf Stream survey was carried out using Expendable Bathothermographs (XBT's) and Conductivity, Temperature and Depth (CTD's). One Vector Averaging Current Meter (VACM) test mooring was launched and a twenty-four hour CTD "yo-yo" experiment was done.

Prepared for: *Office of Naval Research under Contract N00014-74-C-0262; NR 083-004.*

*CRUISE REPORT - CHAIN 109*

George H. Tupper

*CHAIN-109* was a single leg cruise, Woods Hole to Woods Hole, from 4 to 19 December 1972. Seven moorings were recovered, four were launched, and one was launched and immediately recovered as part of a new launch technique, all in the Site D area (39°N, 70°W). Three auto-probe stations were done, five CTD stations were taken, and seven hydrographic stations were taken. An apparent Gulf Stream eddy was found and mapped. Ranging tests of modified acoustic transponders were done by AMF (American Machine Foundary).

Prepared for: *Office of Naval Research under Contract N00014-66-C-0241; NR 083-004.*

*EXPERIMENTAL HYDRODYNAMIC OBSERVATIONS OF TRANSITION PHENOMENA*

John A. Whitehead, Jr.

An overview of some of the scientific literature which reports experimental observations of hydrodynamic instabilities is given. Discussion is limited to those instabilities which lead to non-turbulent motions.

Some comparisons with theoretical predictions are made.

Prepared for: *National Science Foundation under Grant DES 72-01562.*

# GRADUATE STUDENTS



GRADUATE STUDENTS

(Abstracts of papers submitted in 1975 for publication and theses by graduate students in the Woods Hole Oceanographic Institution Doctoral Degree Program and in the Massachusetts Institute of Technology/Woods Hole Oceanographic Institution Joint Program in Oceanography/Oceanographic Engineering.)

## GRADUATE STUDENTS

*AN OCEANIC CALCIUM PROBLEM*

Michael P. Bacon  
(see C-15 for abstract)

*THE CHEMISTRY OF PARTICULATE MATTER COLLECTED BY LARGE VOLUME in situ  
FILTRATION OF THE SURFACE 400m AT 2°N, 9°W IN THE ATLANTIC OCEAN.*

James K. B. Bishop and Michael P. Bacon

Particulate matter was filtered from several cubic meters of seawater using 53 $\mu$  Nitex mesh and a pair of 1 $\mu$  glass fiber filters in series. Chemical analysis for Na, K, Mg, Ca, Sr, Fe, Si, C, N, P, carbonate,  $\delta C^{13}$  organic carbon, Be<sup>7</sup>, Bi<sup>214</sup>, Pb<sup>214</sup>, Pb<sup>210</sup>, Po<sup>210</sup> was supplemented by light and scanning electron microscopy. There is a 20% excess of calcium over carbonate in the upper 100m. K and Mg are enriched relative to Na in particles. These ions have shallow regenerative cycles. S.E.M. shows progressive dissolution of Acantharia with depth and explains the sharp vertical gradient observed for Sr. The Ca and Si profiles may be explained by fragmentation of whole organism tests by zooplankton grazing. C/N ratios of organic matter vary with size and depth: 8,10 > 50 $\mu$ ; 7,9 1-50 $\mu$ ; 5,9 < 1 $\mu$  above and below 100m. Organic carbon  $\delta C^{13}$  shows fractionation from -19.7% to -23.5% between mixed layer and base of the mixed layer and tends to -21% at 400m for the 1-50 $\mu$  fraction. It is decoupled from C/N and C/P ratios and also unrelated to watercolumn T. It occurs at the base of the mixed layer where the greatest populations of diatoms and coccospheres exist. Bi<sup>214</sup> and Pb<sup>214</sup> indicate particulate Ra<sup>226</sup> is carried by either opaline or CaCO<sub>3</sub> particles. Pb<sup>210</sup> and Po<sup>210</sup> and Fe show similar distributions. Be<sup>7</sup> is associated with organic carbon and is not measurable below 100m due to decay. Large particles are progressively enriched with coccoliths and diatom fragments with depth.

Supported by: ONR Contract N00014-75-C-0291.

*A NEW LARGE VOLUME FILTRATION SYSTEM  
FOR THE SAMPLING OF OCEANIC PARTICULATE MATTER*

James K. B. Bishop

A large volume *in situ* filtration system has been developed for the extraction of material greater than one micron in diameter from several cubic meters of water. The system has worked reliably to 400 meters. The particulate matter concentrations determined in profile compare well with those found using conventional Niskin-Nuclepore techniques. By using 53 $\mu$ m Nitex and 1 $\mu$  glass fiber filters in series, the samples are separated into two size fractions. Simple calculations show that the large size fraction contributes a significant proportion of the vertical flux of material and that this proportion increases with surface productivity.

Supported by: ONR Contract N00014-75-C-0291.

*THE SIPHONOPHORE Bathyplysa sibogae LENS AND VAN RIEMSDIJK,  
1908, IN THE SARGASSO SEA, WITH NOTES ON ITS NATURAL HISTORY*

Douglas C. Biggs and G. Richard Harbison  
(see B-13 for abstract)

*ON THE MARINE GEOCHEMISTRY OF NICKEL, EARTH AND PLANETARY SCIENCE LETTERS*

Edward Boyle

The distribution of nickel in the water column of the world oceans is similar to that of the nutrients: the concentration levels range from as low as 3 nanomoles/kg in surface waters to 12 nn/kg in the deep waters of the North Pacific. The form of the Pacific profiles indicates that nickel is regenerated both at shallow depths, like phosphate, and in the deep waters like silicate. The oceanic residence time of nickel is ca. 10,000 years. Although ferromanganese phases the ultimate sink for nickel they control neither its distribution in the water column nor its initial sedimentation.

Supported by: *ONR Contract N00014-75-C-0291 and Doherty Foundation.*

*NORTHWEST AFRICAN SHELF SEDIMENTS:  
INFLUENCE OF CLIMATE AND SEDIMENTARY PROCESSES*

Scott R. Briggs  
(see GG-30 for abstract)

*MOMENTUM, MASS, HEAT, AND VORTICITY BALANCES  
FROM OCEANIC MEASUREMENTS OF CURRENT AND TEMPERATURES*

Harry Leonard Bryden, Jr.

The local dynamics of low-frequency motions in the MODE region are investigated from three arrays of moored measurements of current and temperature. Tests for lowest-order balances of horizontal momentum, mass, heat, and vorticity within estimated errors are carried out.

Geostrophic comparisons of four-day averaged observed and geostrophic current differences from the MODE-1 array indicate that a geostrophic balance within estimated errors is the lowest-order horizontal momentum balance. The discrepancy between observed and geostrophic current differences has a standard deviation of 1.9 cm/sec which is 26% as large as the standard deviation of the current differences. In the mass balance, comparisons of estimates of  $\frac{\partial u}{\partial x}$  and  $\frac{\partial v}{\partial y}$  from the MODE-0 Array 1 indicate that within estimated errors the low-frequency currents are horizontally nondivergent. The standard deviation of horizontal divergence, which is the discrepancy from horizontal nondivergence, is  $.22 \times 10^{-6} \text{ sec}^{-1}$  which is 36% as large as the standard deviation of the estimates of horizontal derivatives of velocity. These tests significantly increase the observational basis for geostrophy and horizontal nondivergence and confirm the validity of the error estimates.

In the heat balance, estimates of horizontal advection of temperature balance local time changes of temperature within estimated errors for the IWEX observations. These estimates have small errors because a representation of horizontal advection of temperature in terms of the speed and turning about the vertical of the horizontal

current is used. The errors are so small that from future measurements it may be possible to estimate the sum of local change plus horizontal advection of temperature and from this sum it may be possible to estimate vertical velocity.

This balance between local change and horizontal advection demonstrates that horizontal advection of spatially-varying features is an important cause of local time changes. The horizontal advection could not be explained in terms of advection by the long time-averaged flow field. This suggests that the local dynamics of low-frequency motions in the MODE region are strongly nonlinear. An indication of energy transfer, which occurs in nonlinear processes, is found in a phase lag so that estimates of horizontal advection lead local changes of temperature. In the context of the baroclinic instability model this phase lag is consistent with the growth of perturbation wave energy by conversion of potential energy contained in the forty-day averaged flow field.

In the vorticity balance, estimates of planetary advection account for only half of the local time change of vorticity for MODE-C Array 1 measurements. Within estimated errors these two terms do not balance, so these observations cannot be explained as manifestations of barotropic Rossby waves alone. Estimates of vortex stretching and horizontal advection of relative vorticity could not be made. A phase lag such that estimates of planetary advection lead local changes of vorticity is consistent in the context of the instability model with an increase in perturbation wave grows, due to the conversion of planetary enstrophy.

Because of the importance of the vorticity balance for understanding the dynamics of low-frequency motions an experiment is suggested to estimate accurately all terms in the lowest-order vorticity balance. From such measurements the energy transfer and enstrophy conversion could also be estimated.

Supported by: *ONR Contracts N00014-66-C-0241; NR 083-004 and N00014-66-C-0262; NR 083-004 and NSF IDOE Grant ID075-03962.*

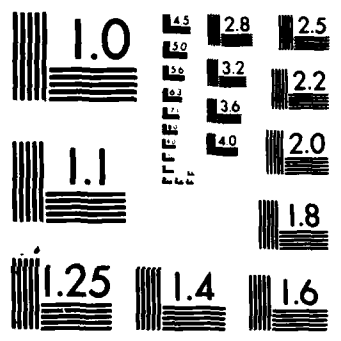
*DISTRIBUTION OF HYDROCARBONS IN A SALT MARSH ECOSYSTEM AFTER  
AN OIL SPILL AND PHYSIOLOGICAL CHANGES IN MARSH ANIMALS FROM THE POLLUTED  
ENVIRONMENT*

Kathryn A. Burns

The studies described in this thesis were designed to answer several problems relating to the recovery of a salt marsh heavily polluted by an accidental spill of Number 2 fuel oil. Field and laboratory studies were conducted for five years comparing the oiled Wild Harbor Marsh with the unoiled Sippewissett Marsh, both on Buzzards Bay in Massachusetts. The data contributes information 1) on the incorporation of oil into the sediments and organisms at the oiled marsh, 2) on the residence times of certain components of the oil in the marsh ecosystem, 3) on changes in chemical composition of the oil with time due to physical and chemical weathering processes and biochemical degradation of hydrocarbons, 4) on the effects of oiled sediments on the population distribution, behavior, and survival of the intertidal fiddler crab, *Uca pugnax*, 5) on the relatively small ability of *Uca* to metabolize hydrocarbons, 6) on the presence of an inducible *in vitro* microsomal mixed function oxidase (MFO) enzyme system in the marsh minnow, *Fundulus heteroclitus*, 7) on the presence of high MFO rates in field populations of *Fundulus* exposed to hydrocarbon pollution, and 8) for the synthesis into a discussion of some of the physiological reasons for the relative sensitivity of marsh animals to oil pollution and their relative ability to adapt to an oil-polluted environment.

Supported by: *The Bureau of Commercial Fisheries Fish & Wildlife Program 14-17-0007-1128(G), The Jesse Smith Noyes Foundation, NSF Doctoral Dissertation Improvement Grant GA-40987, and W.H.O.I.*





MICROCOPY RESOLUTION TEST CHART  
 NATIONAL BUREAU OF STANDARDS-1963-A

*THE STRUCTURAL AND SEDIMENTOLOGICAL EVOLUTION OF THE SOMALI BASIN:  
PALEOOCEANOGRAPHIC INTERPRETATIONS*

Richard H. Burroughs, III

The paleoceanographic development of the Somali Basin in the Northwestern Indian Ocean is determined through considering the structural evolution of the area; its influence on Neogene atmospheric and oceanic circulation as indicated in the sediment record; and variation in these circulation systems as seen in late Quaternary sediments. Chain Ridge forms the main structural element of the Somali Basin. Correlation of geophysical measurements along its topographically elevated portion with geophysical transects in the southern Somali Basin indicates that a buried portion of the Chain Ridge sector of Owen Fracture Zone extends at least to 7.5°S. In areas where crustal age may be estimated on both sides of the fracture zone either by elevation or by other methods, the sea floor to the west is at least 30 m.y. older than that to the east and may be considerably older. The trend of the fracture zone and the age of its segments control the time and direction of movement for India relative to Africa and Madagascar. In addition, they limit the number of proposed reconstructions and indicate that the Western Somali Basin is a small remaining part of the original Tethys. These constraints result in a model for the area which considers Gondwanaland dispersal in the Western Indian Ocean.

The final stages of development of the Somali Basin correspond with the destruction of the Tethys with the final marine regression in northern India during Middle Miocene. Neogene sedimentation rate determinations for the Somali Basin show considerable increases between the Miocene and Recent, in spite of the fact that the basin is becoming larger and deeper. It is proposed that the dessication and subsequent elevation of the area in northern India caused by structural evolution resulted in the development of a land-sea heating contrast which drives the southwest monsoon, and due to increased upwelling and productivity it is recorded by increased sedimentation rates in the Somali Basin.

The late Quaternary sediment record of the area indicates maintenance of these large scale circulations with little change in sea surface temperature as determined from nanofossil assemblage variation, and occurrence of upwelling over a broader area as indicated by the distribution of coarse carbonate. Several significant bottom water incursions into the basin are interpreted from analyzing the total carbonate curves but their effects do not extend to the area of maximum upwelling due to depression of the CCD by high productivity.

Supported by: *ONR Contract N00014-66-C-0241; NR 083-004 and NSF Grant GA-27516.*

*ON THE DYNAMICS OF SHALLOW WATER CURRENTS IN  
MASSACHUSETTS BAY AND ON THE NEW ENGLAND CONTINENTAL SHELF*

Bradford Butman

Massachusetts Bay is a coastal bay 100 km long and 40 km wide located in the western Gulf of Maine. The Bay is closed by land to the north, west and south, but is open to the Gulf to the east; the opening is partially blocked by a shallow bank. The bottom sediment distribution in the Bay is complex; fine grained material is found in the deep basin, sand and gravel on the shallow bank, and mixtures of sand, gravel and fine material near shore. Richardson current meters were moored one meter from the bottom over a one-year period at several locations in the Bay

to study the bottom currents and the equilibrium between current and sediments. The current measurements suggest that the bottom sediments can be expected to move only occasionally in certain areas. The maximum bottom speeds are principally determined by the strong tidal currents in the basin.

In winter, the near-bottom currents are dominated by wind stress associated with strong storms. Bottom currents in the shallow areas are generally in the direction of the wind while currents in the deep portion of the basin are often opposite to the direction of the wind. Sea surface setup in the direction of the wind is observed, as well as absolute changes in sea level as the Bay adjusts to changes in the level of the adjacent Gulf of Maine. Adjustment of the bottom currents to wind events requires approximately 12 hours.

Moored current meter measurements and synoptic hydrographic observations made in Massachusetts Bay show that freshening from the spring runoff dominates the low frequency currents and the hydrography of the Bay in the spring months. The major freshening is attributed to the Merrimack River which empties into the Gulf of Maine 30 km to the north of the Bay; discharge of the Merrimack increases by at least a factor of two in spring. Flow directly into the basin from several smaller rivers is not important. Two major features are found: a fresh surface plume confined to the upper 10 m of the water column which becomes more distinct as the seasonal thermocline develops, and a large deep fresh lens. Flow is clockwise around the deep lens and is consistent with the thermal wind relation. Sustained currents of 10-20 cm sec<sup>-1</sup> with time scales of 5 - 10 days were observed as the deep lens (or lenses) slowly advected through the basin. Current observations made in the previous spring show similar low frequency behavior.

Two simple linear models of the semidiurnal tide on the continental shelf are used to estimate the vertical turbulent eddy viscosity, a linear bottom drag coefficient, and the change in the bottom drag coefficient during storms. The analytic solution for the response of a homogeneous water column with constant eddy viscosity to a sinusoidal body force with a slip bottom boundary condition is presented. With measurements of the tidal current at two depths, four parameters are shown to be independent of the body force: the ratio of the clockwise current at two depths, the ratio of counterclockwise current at two depths, the change in the tidal ellipse orientation, and the change in phase of the tidal ellipse. Observations of the semidiurnal tidal current on the New England continental shelf are consistent with a vertical eddy viscosity of 20 - 50 cm<sup>2</sup>sec<sup>-1</sup> and a bottom drag coefficient of .02 - .05 cm sec<sup>-1</sup>. The Ekman depth is thus 10 m and the integrated adjustment time is approximately 28 hours.

An integrated linear model with linear damping of the semidiurnal tide on the continental shelf, forced uniformly at the shelf edge, shows an increasing phase lag of the tide at the coast with increased damping; amplitude remains relatively constant over a wide range of damping coefficient. Observations of the tide at the coast during storms shows a phase lag of as much as 10 degrees for the semidiurnal tide. For approximate dimensions of the New England shelf, this implies an increase by a factor of 3 - 5 of the bottom drag coefficient and an integrated motion adjustment time of 6 - 9 hours. Waves may be an important contribution to the increased bottom stress.

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*ON THE RELIABILITY OF OCEANIC HEAT FLOW AVERAGES*

John Crowe

One of the major problems in the use of heat flow data in a quantitative manner has been the variability of closely spaced measurements. It is suggested that this variability is directly related to hydrothermal circulation in an 'effectively permeable' oceanic crust. As a consequence, only where this crust is sealed from the seawater by an extensive and thick layer of impermeable sediment can reliable estimates be made of the flux at depth. Heat flow data from such areas are analyzed. It is shown that the scatter in the data is low and that in most areas the mean heat flow through a province of known age is close to that predicted by plate models which account for the increase in depth with increasing age of the ocean floor. From this analysis it is argued that these heat flow means are a reliable estimate of the flux at depth. In order to be able to use heat flow measurements to investigate the age of the crust, the thickness of the lithospheric plate, upper mantle convection, and local anomalies, it is necessary to substantiate this analysis and to find an adequate explanation of the low mean heat flow observed at the center of the sediment bulge in the equatorial Pacific.

Supported by: *NSF Grant DES-73-00513.**ANALYSIS OF A HIGH RESOLUTION DEEP OCEAN ACOUSTIC NAVIGATION SYSTEM*James Leighton Durham  
(see OE-11 for abstract)*OBSERVATIONS OF TEMPERATURE AND VELOCITY MICROSTRUCTURE  
FROM A MOORED ARRAY IN THE MAIN THERMOCLINE NEAR BERMUDA*

Charles C. Eriksen

Measurements of temperature and velocity (vertical as well as horizontal) made on a moored rigid frame 8m high and 20m long in the main thermocline on the slope at Bermuda are discussed in the context of internal wave and microstructure models. Temperature spectra show a marked flattening near the average local buoyancy frequency and display a  $k^{-2}$  or  $k^{-5/2}$  vertical wavenumber dependence in the internal wave range, a flatter dependence at higher frequencies. The frequency of half-coherence  $f_{1/2}$  and vertical separation  $\partial$  vary as  $\partial f_{1/2}^3 = \text{constant}$  for  $\partial \geq 2\text{m}$ ,  $\partial f_{1/2} = \text{constant}$  for  $\partial \geq 1.5\text{m}$ . Velocity and temperature coherences are not inconsistent with shoaling internal waves at moderately high frequencies. Phase lags between sensors indicate coherent displacements at frequencies higher than the time-averaged buoyancy frequency; these are interpreted as internal waves in the fine-structure density gradients. Microstructure and small scale internal waves appear not to be clearly distinguishable phenomena. Temperature-inferred vertical velocity overestimates directly measured vertical velocity at high frequencies.

Supported by: *ONR Contract N00014-75-C-02 1; NR 083-004**THE BEHAVIOR OF A BAROTROPIC EDDY ON A  $\beta$ -PLANE*Eric Firing and Robert C. Beardsley  
(see PO-16 for abstract)

1974 MASSACHUSETTS INSTITUTE OF TECHNOLOGY NEW ENGLAND SHELF DYNAMICS  
 EXPERIMENT (MAR. 1974)  
 DATA REPORT PART 1: HYDROGRAPHY. *Geophysical Fluid Dynamics Rpt.* '75-1, 1975.

Charles N. Flagg

*THE WATER STRUCTURE, MEAN CURRENTS, AND SHELF-WATER/SLOPE-WATER FRONT  
 ON THE NEW ENGLAND CONTINENTAL SHELF*

Charles N. Flagg

A field experiment was conducted during March 1974 to study the structure and variability of the winter hydrography and currents on the New England Continental Shelf. This experiment consisted of a moored current meter array, a series of four hydrographic surveys, and the collection of meteorological data to document the wind forcing. We present here a summary of the winter structure of the New England shelf water, together with a discussion of the most prominent feature of the winter hydrography, the front between the shelf and slope waters. Our data indicates that contrary to the historical conception, the shelf exhibits a well-defined temperature-salinity correlation and moreover this correlation remained approximately constant over the duration of the one-month experiment which occurred during the period of the seasonal extreme. Because of the well-defined T-S correlation, a census based upon quasi-synoptic temperature and salinity data is compiled for the region from Hudson Canyon to Nantucket Shoals out to the 200 meter isobath. The spatial and temporal fluctuations of the wintertime shelf-slope water front are presented. We also present for completeness a description of the seasonal cycle of the New England Continental Shelf waters. A summary of recent direct measurements of "mean" (time-averaged) currents for the New England shelf, slope, and rise region are presented. Our data for the New England shelf show net westward (alongshore) mean currents which generally increase in magnitude in the offshore direction and decrease with depth out to the shelf-slope water front. While not conclusive, our data does not confirm the 10 cm/sec geostrophic shear predicted to occur across the shelf-slope on the basis of the observed mean density field.

Supported by: NSF Grant GA-41075.

*DYNAMICS OF BOUNDARY-LAYER DEPOSITION: A FLUME INVESTIGATION*

Wilford A. Gardner

A recirculating seawater flume was run at temperatures from 30°C to 3°C with suspended concentrations of oceanic sediments of less than 5 mg/l to investigate (1) suspended particle and floc size versus boundary shear stress and suspensate concentration and (2) sedimentation rates as a function of boundary shear stress, viscosity, and concentration of suspended sediment. Suspensate concentration was monitored by standard filtration techniques and with a Model TA II Coulter Counter. The Coulter Counter was also used with an ultrasonification technique to monitor particle and floc size. Initial deposition of sediment introduced into the flume was still rapid at velocities as high as 20 cm/sec as would be measured 1 m off the sea floor ( $\tau_0 = 0.46 \text{ dynes/cm}^2$ ), but appeared to approach an equilibrium concentration after half a day. The difference in rates of deposition in experiments run at different temperatures is greater than can be attributed to the changes in settling rates of particles due to viscosity differences. A model for the transfer of particles through the zone of turbulence and viscous sublayer of the boundary layer is presented.

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*FLUME EXPERIMENTS ON FINE-SEDIMENT DEPOSITION IN THE OCEAN*

Wilford D. Gardner

A sea-water flume was used to simulate oceanic conditions and study 1) rates of flocculation and 2) size of suspended particles and flocs as a function of boundary shear stress and suspended sediment concentration. Experiments were temperature-controlled down to 3°C, with filtered surface water from the Sargasso Sea and sediment from the Blake-Bahama Outer Ridge with mean size 2.6  $\mu$  and < 10% carbonate. Sediment concentration was monitored by standard filtration techniques; size distributions were analyzed with a Coulter Counter. Comparison of size distribution before and after ultrasonic disaggregation showed dependence of flocculation on shear velocity  $u_*$  and concentration. With  $u_* = 0.5$  cm/sec ( $U_{100\text{cm}} = 7.3$  cm/sec), nearly 100% of particles > 3  $\mu$  deposited within 96 hr; with  $u_* = 1.2$  cm/sec ( $U_{100\text{cm}} = 21$  cm/sec), maximum particle size remaining in suspension after 105 hr was 4  $\mu$ . This suggests that particles > 3-4  $\mu$  in the boundary layer which either have been re-suspended or have settled through the water column can be expected to travel only km to 10's of km before being deposited. To account for non-turbidite silt-size material in the deep ocean one must thus appeal to frequent resuspension, significant eolian transport, or periods with current velocities significantly higher than present-day averages ( $U_\infty = 5-10$  cm/sec). Higher velocities would both transport terrigenous particles greater distances from land while settling through the water column and maintain larger particles in suspension for longer times.

Supported by: *ONR Contracts N00014-67-A0204-0048, N00014-75-C-0291, N00014-74-C-0262 and N00014-74-C-0241)*

*SEDIMENT DYNAMICS OF THE EASTERN CORNER OF THE NORTHERN BERMUDA RISE*

Wilford D. Gardner

The results of a program of detailed seismic profiling and coring conducted in a small area (6400 km<sup>2</sup>) on the eastern corner of the northern Bermuda Rise indicate that this region can no longer be considered an environment of tranquil, pelagic sedimentation. Rapid deposition and erosion from bottom currents, massive slumping of bottom current deposits, pelagic sedimentation, and deposition from turbidity currents are all features of the regional pattern of sediment dynamics. The most important feature is the rapid deposition of terrigenously derived fine silts and clays from bottom currents flowing over a gently rolling plateau elevated above the Sohm Abyssal Plain. For the past 127,000 years average accumulation rates have been about 20 cm/1000 years with one episode between 11,500 and 13,090 years that exceeded 150cm/1000 years. We speculate that the terrigenously derived material has been injected into the deep oceans primarily during periods of continental glaciation and then transported and deposited by the clockwise gyre of AABW around Bermuda. The episode of high accumulation may be related to the switching of melt water drainage from the Mississippi to the Hudson and the St. Lawrence.

Supported by: *ONR Contracts N00014-67-A0204-0048, N00014-75-C-0291, N00014-74-C-0262 and N00014-74-C-0241)*

SEA-BIOSPHERE INTERFACE:  
PETROLEUM AND BIOGENIC HYDROCARBONS IN THE SARGASSUM COMMUNITY

Joy Geiselman

Samples of *Sargassum* and its associated fauna were collected on 18 occasions between 1972 and 1975. In addition to *Sargassum natans* and *Sargassum fluitans*, most of the larger animals were separated, including crabs, shrimps, a fish, a nudibranch and a gastropod. When sufficient material had been accumulated, the samples were extracted and the non-polar hydrocarbons analyzed by gas chromatography. A large biogenic peak near the retention time of the normal C<sub>17</sub> alkane was present in most chromatograms, and other chromatograms also showed large peaks at C<sub>15</sub> and C<sub>19</sub> which were almost certainly biogenic. Essentially all samples showed also the typical pattern of a paraffinic crude oil, with a full set of normal paraffins from C<sub>17</sub> to C<sub>35</sub> without any distinctively large peaks or odd/even preference and an unresolved envelope beneath the paraffin peaks. Total hydrocarbon contents varied from 8 to 3400 µg/g dry weight, and the ratio of petroleum to biogenic hydrocarbons varied from 12 to 600. Petroleum hydrocarbons present in high concentrations were probably ingested directly as tar particles: the crab *Planes minutus*, for example, was observed to ingest tar in the laboratory. The other organisms apparently partitioned hydrocarbons (typically 100 µg/g) from the surrounding water or sea surface microlayer, and except for the relatively lower petroleum hydrocarbon content (10-20 µg/g) of the *Sargassum*, position in the food web did not seem to correlate with petroleum hydrocarbon content. This can be attributed partly to the many alternative food sources used by the higher animals and the consequent blurring of the trophic levels.

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THE GENERATION, ENERGETICS AND PROPAGATION OF INTERNAL TIDES  
IN THE WESTERN NORTH ATLANTIC OCEAN

Ross MacRae Hendry

This thesis reports on an investigation into the structure, energetics and propagation of tidal frequency internal waves. Data from Site D, near the New England continental slope, Muir Seamount northeast of Bermuda, and the Mid-Ocean Dynamics Experiment in the deep Sargasso Sea were used.

Site D, in the near-field of a near-critical semidiurnal generation region, shows variable tidal currents and a marked surface intensification of M<sub>2</sub> energy at the southern Site, related to the beam-like nature of the internal tide. The M<sub>2</sub> tide dominates the semidiurnal band, with about three times more energy than at adjacent frequencies at 1/15 cpd separation. There is a significant phase locking between the M<sub>2</sub> baroclinic currents and the equilibrium tide, and evidence for southward propagation of internal wave energy, suggesting generation at the slope to the north. The M<sub>2</sub> baroclinic energy density is about 40% as great as the total barotropic energy density, but the internal tides have more horizontal kinetic energy. A seaward energy flux of  $.6 \times 10^6$  erg/s cm in the first three baroclinic M<sub>2</sub> modes is much less than the  $.2 \times 10^{10}$  erg/s cm shoreward energy flux in the surface tide. Difficulties in interpreting the measurements are ascribed to the near-singular generation case.

The MODE-1 semidiurnal internal tides are also dominated by the M<sub>2</sub> frequency, with a three-fold energy increase over adjacent frequencies at 1/15 cpd separation. MODE-1 is far from any major source of internal tides, but the measurements are

much less variable than those from Site D. The extensive temperature measurements defining the MODE-1  $M_2$  internal tide are significantly coherent (phase locked) with the equilibrium tide, with about 80% of the coherent energy deriving from the first baroclinic mode, typical thermocline displacements being 3 m. A horizontal wave-number spectrum estimate for the first mode  $M_2$  displacement fluctuations gives a peak at 160 km wavelength, in excellent agreement with the theoretical dispersion relation. The coherent first mode propagates on a bearing of  $125^\circ T$ , with a horizontal energy flux of  $.3 \times 10^8$  erg/s cm. Use of the weaker  $S_2$  internal tide and the dispersive nature of oceanic internal waves yields an estimate of 700 km to a common semidiurnal source region. The inferred range and bearing are consistent with generation at the Blake Escarpment and the continental slope to the northwest of the experiment. In one special case current and temperature measurements are combined in a local demonstration of the first mode  $M_2$  propagation, and the less extensive current data gives estimates of the barotropic tidal currents.

Mooring motion, measured by pressure recorders on the mooring lines, accounts for about 15% of the semidiurnal temperature variance, but it is incoherent with the equilibrium tide.

Diurnal tides were examined at all three locations. At the MODE\_1 site - near the critical latitude for diurnal period internal waves - the current and temperature fields are dominated by high mode, incoherent, inertial-character motions which mask the tidal currents. About 25% of the diurnal band temperature variance is related to mooring motion. Muir Seamount provides a clear example of diurnal period internal tides trapped to their source region north of the critical latitude. A simple analytical model is developed for the diurnal period flow adjustment in a seamount geometry. Site D shows some evidence for diurnal period internal tides, but most of the energy in the diurnal currents is not simply related to the tidal forcing. Diurnal barotropic currents measured at Site D are combined with currents on the New England shelf, showing that the diurnal tidal wave behaves as a Kelvin-Stokes mode trapped to the slope, propagating along the depth contours to the west.

Some aspects of simple generation models are considered. The slope north of Site D is not at all well-described as an abrupt step for the  $M_2$  generation problem, but a more realistic model of Baines (1974) predicts the coherent fields observed. But the relatively small energy conversion from the surface tide to internal modes suggests that the globally near-critical slope north of Site D is a poor generator of internal tides in the deep sea, although the local energy density is high. The step shelf generation model is well suited for the steep Blake Escarpment, and predicts a seaward energy flux of  $.4 \times 10^8$  erg/s cm in the first mode, comparable to the measurements at MODE-1. This confirms theoretical expectations that the first baroclinic mode is not significantly damped by turbulent diffusion after propagating through the 700 km of ocean between the generation region and the MODE-1 deep ocean site.

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*ELEMENTAL FLUXES DURING HYDROTHERMAL ALTERATION OF BASALTS*

Susan E. Humphris  
(see C-4 for abstract)

*GULF STREAM COLD CORE RINGS: LARGE SCALE INTERACTION SITES  
FOR OPEN OCEAN PLANKTONIC COMMUNITIES*

Andrew E. Jahn (collaborator)  
(see B-19 for abstract)

*NOTES ON THE PELAGIC SQUALOID SHARK, Isistius brasiliensis*

Andrew E. Jahn  
(see B-30 for abstract)

*SPERM WHALES (Physeter catodon) REACT TO PINGERS*

Andrew E. Jahn (collaborator)  
(see B-42 for abstract)

*INSTABILITY AND ENERGETICS IN A BAROCLINIC OCEAN*

Kuh Kim

This thesis is made of two separate, but interrelated parts.

In Part I the instability of a baroclinic Rossby wave in a two-layer ocean of inviscid fluid without topography, is investigated and its results are applied in the ocean. The velocity field of the basic state (the wave) is characterized by significant horizontal and vertical shears, non-zonal currents, and unsteadiness due to its westward propagation. This configuration is more relevant to the ocean than are the steady, zonal 'meteorological' flows, which dominate the literature of baroclinic instability. Truncated Fourier series are used in perturbation analyses.

The wave is found to be unstable for a wide range of the wavelength; growing perturbations draw their energy from kinetic or potential energy of the wave depending upon whether the wavelength,  $2\pi L$ , is much smaller or larger than  $2\pi L_0$ , respectively, where  $L_0$  is the internal radius of deformation. When the shears are comparable dynamically,  $L \sim L_0$ , the balance between the two energy transfer processes is very sensitive to the ratios  $L/L_0$  and  $U/C$  as well, where  $U$  is a typical current speed, and  $C$  a typical phase speed of the wave. For  $L = L_0$  they are augmenting if  $U < C$ , yet they detract from each other if  $U > C$ .

The beta-effect tends to stabilize the flow, but perturbations dominated by a zonal velocity can grow irrespective of the beta-effect.

It is necessary that growing perturbations are comprised of both barotropic and baroclinic modes vertically. The scale of the fastest growing perturbation is significantly larger than  $L$  for barotropically controlled flows ( $L < L_0$ ), reduces to the wave scale  $L$  for a mixed kind ( $L \sim L_0$ ) and is fixed slightly larger than  $L_0$  for baroclinically controlled flows ( $L > L_0$ ).

Increasing supply of potential energy causes the normalized growth rate,  $\alpha L/U$ , to increase monotonically as  $L \rightarrow L_0$  from below. As  $L$  increases further beyond  $L_0$ , the growth rate  $\alpha L_0/U$  shows a slight increase, but soon approaches an asymptotic value.

In a geophysical eddy field like the ocean this model shows possible pumping of energy into the radius of deformation ( $\sim 40$  km rotational scale, or 250 km wavelength) from both smaller and larger scales through nonlinear interactions, which occur without interference from the beta-effect. The e-folding time scale is about 24 days if  $U = 5$  cm/sec and  $L = 90$  km. Also it is strongly suggested that, given

the observed distribution of energy versus length scale, eddy-eddy interactions are more vigorous than eddy-mean interaction, away from intense currents like the Gulf Stream. The flux of energy toward the deformation scale, and the interaction of barotropic and baroclinic modes, occur also in fully turbulent 'computer' oceans, and these calculations provide a theoretical basis for source of these experimental cascades.

In Part II an available potential energy (APE) is defined in terms appropriate to a limited area synoptic density map (e.g., the 'MODE-I' data) and then in terms appropriate to time-series of hydrographic station at a single geographic location (e.g., the 'Panulirus' data).

Instantaneously the APE shows highly variable spatial structure, horizontally as well as vertically, but the vertical profile of the average APE from 19 stations resembles the profile of vertical gradient of the reference stratification. The eddy APE takes values very similar to those of the average kinetic energy density at 500 m, 1500 m and 3000 m depth in the MODE area.

In and above the thermocline the APE has roughly the same level in the MODE area (centered at 28°N, 69°40'W) as at the Panulirus station (32°10'N, 64°30'W), yet in the deep water there is significantly more APE at the Panulirus station. This may in part indicate an island effect near Bermuda.

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*THE INFLUENCE OF MEAN STRESS AND NOTCHES ON THE  
CORROSION FATIGUE BEHAVIOUR OF A HIGH STRENGTH ALUMINUM ALLOY*

John R. Kreider

A study of the corrosion fatigue behaviour of aluminum alloy 7075-T6 in air and in 0.5N NaCl has been undertaken. The results of tests with notched and unnotched samples fatigued in both environments were used to quantify the effects of U-shaped notches and mean stress on fatigue life. Results in air indicate that to maintain a constant fatigue life, the applied cyclic stress range must be decreased in accordance with Gerber's Parabola as the mean stress is increased. In 0.5N NaCl, the fatigue strength is independent of the mean stress for stress ratios between 0.1 and 0.8. A simple equation relating the calculated maximum stress at the notch root and the number of cycles for initiation of a fatigue crack is presented. A mechanism for calculating the number of cycles required to propagate a crack from initiation to catastrophic failure is also proposed. Use of these two relationships enables the design engineer to predict the total fatigue life of any marine structure for which stress concentration factors can be calculated.

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THE CONVERSION OF DIHYDRONEOPTERIN TRIPHOSPHATE TO SEPIAPTERIN  
BY AN ENZYME SYSTEM FROM *Drosophila melanogaster*

Gwen G. Krivi

The enzyme system for the synthesis of the pteridine pigment, sepiapterin, from 2-amino-4-hydroxy-6-(D-erythro-1',2',3'-trihydroxypropyl)7,8-dihydropteridine triphosphate (dihydroneopterin triphosphate) has been found in extracts of *Drosophila melanogaster*. NADP<sup>+</sup> or NADPH and Mg<sup>2+</sup> are required for this enzymatic transformation. No sepiapterin is produced when dihydroneopterin is supplied as substrate in place of dihydroneopterin triphosphate.

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THE VERTICAL PROPAGATION OF INERTIAL WAVES IN THE OCEAN

Kevin Douglas Leaman

A set of vertical profiles of horizontal ocean currents, obtained by electromagnetic profilers in the Atlantic Ocean southwest of Bermuda in the spring of 1973, has been analyzed in order to study the vertical structure and temporal behavior of internal waves, particularly those with periods near the local inertial period. An important feature of the observed structure is the polarization of horizontal velocity components in the vertical. This polarization, together with temporal changes of the vertical wave structure seen in a time series of profiles made at one location, has been related to the direction of vertical energy flux due to the observed waves. Whereas the observed vertical phase propagation can be affected by horizontal advection of waves past the point of observation, the use of wave polarization to infer the direction of vertical energy propagation has the advantage that it is not influenced by horizontal advection. The result shows that at a location where profiles were obtained over smooth topography, the net energy flux was downward, indicating that the energy sources for these waves were located at or near the sea surface. An estimate of the net, downward energy flux ( $\sim .2 - .3$  erg/cm<sup>2</sup>/sec) has been obtained. Calculations have been made which show that a frictional bottom boundary layer can be an important energy sink for near-inertial waves. A rough estimate suggests that the observed, net, downward energy flux could be accounted for by energy losses in this frictional boundary layer. A reflection coefficient for the observed waves as they reflect off the bottom has been estimated.

In contrast, some profiles made over a region of rough topography indicate that the rough bottom may also be acting to generate near-inertial waves which propagate energy upward.

Calculations of vertical flux of horizontal kinetic energy, using an empirical form for the energy spectrum of internal waves, show that this vertical flux reaches a maximum for frequencies 10% - 20% greater than the local inertial frequency. Comparison with profiler velocity data and frequency spectra supports the conclusion that the dominant waves had frequencies 10% - 20% greater than the inertial frequency. The fact that the waves were propagating energy in the vertical is proposed as the reason for the observed frequency shift.

Finally, energy spectra in vertical wave number have been calculated from the profiles in order to compare the data with an empirical model of the energy density spectrum for internal waves proposed by C. Garrett and W. Munk (1975). The result



shows that although the general shape and magnitude of the observed spectrum compares well with the empirical model, the two-sided spectrum is not symmetric in vertical wave number. This asymmetry has been used to infer that more energy was propagating downward than upward. These calculations have also been used to obtain the coherence between profiles made at the same location, but separated in time (the so-called dropped, lagged, rotary coherence). This coherence is compared with the aforementioned empirical model. The coherence results show that the contribution of the semidiurnal tide to the energy of the profiles is restricted to long vertical wave lengths.

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*MAGNETIC ANOMALIES IN THE WEST PHILIPPINE BASIN*

Keith E. Louden  
(see GG-17 for abstract)

*HEAT FLOW, DEPTH AND CRUSTAL THICKNESS OF THE MARGINAL BASINS OF THE SOUTH PHILIPPINE SEA*

Keith E. Louden

We present 51 heat flow measurements and two geophysical profiles across the West Philippine and Parece Vela Basins. We show that both regions have a variable heat flow but that the scatter decreases markedly if we accept as reliable only measurements in areas of uniform sediment drape. Extending this argument to the deep ocean floor shows that the heat flow in these two marginal basins is not necessarily higher than for deep ocean floor of the same age. On the other hand the mean depth of both basins is greater and the oceanic crust thinner than that for ocean floor of the same age. In the absence of a significant free air gravity anomaly over both basins we suggest that age thinner crust may account for most of the increase in depth of the two basins. However, more refraction studies are needed to substantiate this difference before this explanation can be unreservedly accepted.

Supported by: *ONR Contract N00014-67-A-0204-0048*)

*THERMAL CONDUCTION ACROSS FRACTURE ZONES AND THE GRAVITATIONAL EDGE EFFECT*

Keith E. Louden

We solve the two-dimensional, time-dependent heat flow equation across an idealized fracture zone boundary, which includes the process of lateral heat conduction across an initially abrupt temperature contrast. From this solution we can calculate the temperature field for any initial offset and at any sequential time. We can use this to calculate the free-air gravity anomaly across the fracture zone given an assumed density variation with temperature. Results for a 30 m.y. initial offset show that both the amplitude and the shape of the anomaly are significantly altered by lateral heat conduction across the fracture zone even during the first few million years. Assumptions of a sharp density contrast across fracture zones are therefore only valid in very restricted regions close to the ridges. We also find that the theoretical anomaly is small when compared to observations. These results add significant complications to attempts at finding unique models for the structure of the lithosphere from gravitational anomalies across fracture zones.

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*TRANSIENT STRUCTURE IN BENTHIC COMMUNITIES  
The Effects of Oxygen Stress, Burial and High  
Rates of Sedimentation*

Jean Nichols-Driscoll

The influence of natural short-term fluctuations in environmental parameters on three components of transient benthic invertebrate community structure: abundance of individuals and species, biomass of individuals, and species diversity, were investigated in this study. The effect of low dissolved-oxygen on transient benthic community structure was studied with samples from Golfo Dulce, an intermittently anoxic basin off the west coast of Costa Rica and the Fosa de Cariaco, an anoxic trench off the north coast of Venezuela. Periodic fluctuations in oxygen concentration were accompanied by a community numerically dominated by a single polychaete species and low species diversity. As the frequency of fluctuations in oxygen concentration decreased, the number of species and individuals in the community increased with a corresponding increase in species diversity.

In contrast to fluctuating oxygen conditions which eliminated many species from the community, fluctuating amounts of suspended matter in the bottom water allowed one species to proliferate while maintaining the total species list length. High rates of terrigenous sedimentation occurring naturally off the Spanish Sahara coast produced conditions which apparently hampered the feeding mechanisms of a spionid polychaete. Further offshore, where the diversity should be expected to increase, the spionids were able to flourish. The result was greater numerical abundance and biomass offshore and a lower transient diversity value. Results of simulation of catastrophic burial by *in situ* burial of small isolated portions of Buzzards Bay sediment indicated that sedimentation rates recorded off Spanish Sahara would not eliminate species by burial. However, the small size of the organisms found off Spanish Sahara is probably a result of the constant expenditure of energy for escape.

In regions of fluctuating environmental conditions, diversity values are low, principally because of dominance by a single species. Increasingly stable conditions, even though stressful, result in a more even distribution of individuals among the species present and a correspondingly high transient value.

Supported by: *W.H.O.I. Fellowship and NSF Grants GA-36551 and GA-33502.*

*THE ESCAPE OF VELIGERS FROM THE EGG CAPSULES OF Nassarius obsoletus  
AND Nassarius trivittatus (GASTROPODA, PROSOBRANCHIA)*

Jan A. Pechenik  
(see B-22 for abstract)

*THE BOUVET TRIPLE JUNCTION*

John Peirce  
(see GG-17 for abstract)

## ASSESSING RELIABILITY OF DSDP PALEOLATITUDE

John Peirce

Published DSDP paleomagnetic data are reviewed and reevaluated in terms of their reliability for paleolatitude calculations. Where possible, new paleolatitudes are calculated from data which were originally used only for paleomagnetic stratigraphy. For basalts, new paleolatitudes are calculated by averaging the data by cooling unit if this was not done previously. In addition, all paleolatitudes are corrected by a small amount because inclination averages without declination control provide low estimates of the true paleolatitude. Standard rating criteria are developed and all paleolatitudes are rated accordingly.

Rarely do DSDP paleolatitudes approach the reliability of good continental pole positions. A paleolatitude determination for a given age at a single DSDP site cannot be considered reliable even if the data on which it is based are coherent. However, the reliability of such paleolatitudes can be markedly improved by using comparisons with paleolatitudes of different ages from the same site, paleolatitudes of similar ages from different sites on the same plate, estimates of paleolatitude from reconstructions based on marine magnetic anomalies, and continental paleopole positions.

A newly calculated paleomagnetic pole for the Pacific plate has been defined by six DSDP sites of upper Cretaceous age. The pole at  $61^{\circ}\text{N}$ ,  $45^{\circ}\text{W}$  is generally consistent with other estimates of Pacific plate motion.

A pole for the Wharton Basin (eastern Indian Ocean) has been defined by four sites of middle Cretaceous age. The pole position at  $55^{\circ}\text{S}$ ,  $165^{\circ}\text{E}$  is well-constrained in latitude, and it suggests that there may have been left lateral motion between the Wharton Basin and the Australian continent.

Basement paleolatitudes from four sites on the Ninetyeast Ridge in the Indian Ocean all are close to  $50^{\circ}\text{S}$ , although they range widely in age. This supports the hypothesis that the Ninetyeast Ridge may be a volcanic trace from a hotspot.

Supported by: *W.H.O.I. Fellowship and NSF Grant DES 74-22552.*

## GEOSTROPHIC CALCULATIONS FOR THE ALBORAN SEA

David L. Porter

Geostrophic calculations from CTD (conductivity, temperature, depth) (Woods Hole Oceanographic Institution/Brown University CTD) stations near the Strait of Gibraltar are examined in an effort to determine the origins of the water leaving the Mediterranean Sea and the circulation in the western Alboran Sea. The data consists of three sections taken in February 1975; one east-west section along the axis of the Strait and two separate north-south sections starting and ending at about the 300 m depth contour. Special attention is given to the choice of a level of no motion.

Supported by: *ONR Contract 10/241.11.*

## OBSERVATIONS OF HOMOGENEOUS BOTTOM LAYERS IN THE WESTERN NORTH ATLANTIC

James G. Richman

The presence of bottom layers of constant potential temperature and salinity is examined in 87 CTD stations taken during 1973 and 1974 in the western North Atlantic. The average layer thickness is 32 m with a standard deviation of 24 m. No layer was observed in 6 stations and the thickest layer observed was 144 m. Concurrent with the CTD measurements 12 current meters and 8 temperature recorders were moored 100 m above the bottom for 3 months. The estimated Ekman layer thickness  $u_* / f$  from the current meters is 17 m. The temperature of the bottom layer adjusted for the observed depth of the station is inversely correlated with the layer thickness. The potential temperature above the layer is positively correlated with the layer thickness. The layer appears to increase on time scales of a day and persist over longer times. Large spatial gradients in the bottom temperature are observed. The mechanisms of horizontal advection and convergence and divergence of a turbulent Ekman layer are suggested to explain discrepancies between the observed layer thickness and temperature and locally mixed turbulent Ekman layer theory.

Supported by: *Hertz Fellowship*

## COHERENCE MODEL FOR MODE EDDY LENGTH AND TIME SCALES

James G. Richman

The eddy length and time scales are examined from the spectra of moored temperature and velocity obtained during the Mid-Ocean Dynamics Experiment (MODE). The wavenumber spectrum of temperature has a broad peak at a wavelength of  $350 \pm 50$  km to the northwest in the main thermocline and less defined shorter wavelength peaks in the deep water. The frequency spectra exhibit similarity at all depths for periods less than 50 days attenuating as  $\omega^{-2.5}$ . At lower frequencies, the spectra in the deep water level off, exhibiting shorter time scales than in the main thermocline. The vertical coherence of the temperature is high for periods greater than 30 days. The horizontal coherence of the temperature is higher in the main thermocline than in the deep water. The vertical structure of the temperature and velocity is calculated and decomposed into vertical modes with 60% of the potential energy in the first baroclinic mode and 30% of the kinetic energy in the barotropic mode. Comparisons are made with linear and weakly nonlinear wave fits and the importance of horizontal advection of temperature assessed.

Supported by: *Hertz Fellowship*SMALL DEEP DIVING SUBMERSIBLE DESIGN IN  
RELATION TO EXISTING AND FUTURE TECHNOLOGY

George Rodenbusch

This paper explores the impact of present and near-future technological advances on six advanced submarine designs as well as the DSRV design. The six advanced designs include a 5-knot, 10-knot and 15-knot, 12,000-foot collapse depth

submarine of about 500 miles endurance, and a 6-knot, 12-knot and 18-knot, 30,000-foot collapse depth submarine of about 3,600 miles endurance. The technological advances considered are those in energy sources and power plants, pressure hull materials, and flotation systems.

The results show that only the 5-knot, 500-mile, 12,000-foot collapse depth submarine is feasible with the technological advances foreseeable within the coming year. Development of the 15-knot sprint speed submarine of this group is possible only if the Lithium Water Cell energy source is developed. No other long-term technological advances are needed for this submarine. Some of the other foreseeable technological advances in energy sources also offer the possibility of a 10-knot submarine with a 500-mile endurance and a 12,000-foot collapse depth.

Development of an 18-knot sprint speed submarine of 3,600-mile endurance and 30,000-foot collapse depth is possible if both a fused alumina flotation system along with a Zirconium Hydroids- $UO_2$  Brayton Cycle nuclear power plant are successfully developed. Either this plant or the Lithium Water Cell plant would permit development of a 12-knot cruise and sprint speed submarine of 3,600 miles endurance and 30,000-foot collapse depth with currently available pressure hull and flotation materials.

Supported by: *NSF Fellowship*

*RESONANT INTERACTIONS AMONG BAROCLINIC INERTIO-GRAVITY AND ROSSBY WAVES*

Barry R. Ruddick  
(See PO-13 for abstract)

*METHANE IN THE NEAR SURFACE WATERS  
OF THE WESTERN SUBTROPICAL NORTH ATLANTIC*

Mary I. Scranton

Methane profiles collected from the western subtropical North Atlantic show maxima in a zone of sharp density contrast which lies immediately above the regional salinity maximum. Open ocean surface waters have methane concentrations 48%-67% higher than concentrations predicted from solubility equilibrium with the atmosphere, while concentrations at the maximum may reach 1.9 to 2.5 times the equilibrium solubility. Physical transport processes may be important in carrying methane from coastal areas into the open ocean, and thus in supplying methane to the maximum. Several observations, however, suggest that *in situ* biological production is also important in determining the methane distribution in the near surface waters of the western subtropical North Atlantic.

Supported by: *NSF Grant DES75-02731.*

*ANALYSIS AND IMPLICATIONS OF THE SEQUENCE OF RIDGE JUMPS THAT  
ELIMINATED THE SURVEYOR TRANSFORM FAULT*

John Shih

By using magnetic anomaly data from a detailed geophysical survey west of the

Juan de Fuca rise between longitudes  $143^{\circ}\text{W}$ - $134^{\circ}\text{W}$  and latitudes  $42^{\circ}\text{N}$ - $48^{\circ}\text{N}$  the history of spreading at the Pacific-Farallon spreading center in this region can be reconstructed for the period 35-20 m.y. ago (anomalies 12-5E). During this time period, relative migration of spreading axes separated by transform faults resulted in the elimination of the offset represented by the Surveyor fracture zone. Magnetic anomalies in the southern part of the region require eastward jumps of spreading centers of between 40 and 50 km, and those in the northern part imply westward jumps of up to 70 km. The locations of the spreading center jumps migrate along spreading axes with time, concurrently with northward or southward jumps of transform faults, and leave zones of extensively sheared crust with unidentifiable magnetic anomaly patterns in the crust between old and new spreading centers. Such a process may account for the disturbed zone of magnetic anomalies between the Murray and Molokai fracture zones and could be common to all ridge jumps. If so, it suggests that the new spreading centers do not begin simultaneously over long lengths but instead develop in a manner somewhat similar, but not identical, to a crack propagating through a solid.

Supported by: *W.H.O.I. Fellowship and NSF Grant DES14-02636*

*SURFACE OZONE IN THE SOUTH EAST ATLANTIC BETWEEN DAKAR AND WALVIS BAY*

Robert F. Stallard

A continuous section of surface ozone concentration in the eastern equatorial and southern tropical Atlantic shows maximum values (30-48 ppbV) in the ITCZ with low uniform values (13-15 ppbV) in the southeast trades. The high values are associated with mesoscale downdrafts in the convergence region. The southerly data show diurnal variations with night-time maxima the amplitude of which increases landwards. These are probably caused by atmospheric cooling over the warm ocean.

Supported by: *NSF Fellowship.*

*THE CHARACTERIZATION OF HUMIC SUBSTANCES IN SEAWATER*

Daniel H. Stuermer

Humic substances were isolated in gram quantities from seawater by newly developed procedure of adsorption on a crosslinked polystyrene-divinylbenzene resin. The chemical and physical characteristics of both humic acid and fulvic acid fractions were studied.

The elemental composition, the acidimetric titration characteristics, the  $13\text{C}:12\text{C}$  ratios, and the ultraviolet, visible, fluorescence, and infrared spectra were determined. Molecular weight distributions of coastal and Sargasso Sea fulvic acids were measured by gel permeation chromatography. Structural features were further investigated by both proton and carbon-13 nuclear magnetic resonance spectroscopy. In addition, the fulvic acids and their derivatives were analyzed by low and high resolution mass spectrometry and combined gas chromatography-mass spectrometry (GC-MS). Amino acids and organic solvent-soluble products in acid hydrolyzates were investigated. An array of biogenic hydrocarbons produced from fulvic acid by a new reduction scheme were characterized by GC-MS.

The structural features of seawater humic substances are complex. They are highly aliphatic, polyfunctional materials containing both polar and nonpolar moieties. Hydrolyzable amino acids constitute a low percentage of the nitrogen. Fatty acids and other lipids are important structural components. Seawater humic substances have significant structural differences from those of terrestrial origin; this seems to result mainly from the relatively low input of lignin to the marine environment and the differences between the physical environment of the soil and the sea.

A mechanism is proposed for the formation of seawater humic substances from amino acids, sugars and lipids. The effects and fate of humic substances in the sea are discussed.

Supported by: *W.H.O.I. Fellowship, Arthur Vining Davis Foundation and the National Science Foundation Grant GA-36631*)

*CREEP BUCKLING OF SHELLS OF REVOLUTION LOADED UNDER UNIFORM EXTERNAL PRESSURE*

Paul Francis Sullivan

A theoretical investigation is undertaken into the creep instability of two common shells of revolution, the infinitely long cylinder and the complete sphere. The linear and nonlinear visco-elastic material idealizations are used in the various theoretical procedures. The critical buckling time is greatly influenced by the parameter  $a/h$  ratio, magnitude of initial imperfections and material selection. The spherical shell has a lifetime longer than the cylindrical shell having the same  $a/h$  ratio, initial imperfections and material constants, while the critical mode numbers are the same.

Supported by: *Burke Scholar, United States Navy.*

*THE RELATIONSHIP BETWEEN CUPRIC ION ACTIVITY AND  
THE TOXICITY OF COPPER TO PHYTOPLANKTON*

William Sunda

The purpose of this investigation is to quantify the relationship between cupric ion activity and the toxicity of copper to phytoplankton and further to study the effect on copper toxicity of naturally occurring organic ligands.

Culture experiments with an estuarine diatom *Thalassiosira pseudonana* (clone 3H) in highly chelated seawater media demonstrated that copper induced growth rate inhibition and 3 to 4 day cellular uptake of copper are both related to the calculated free cupric ion activity and are independent of the total copper concentration. Cupric ion activity and total copper concentration were independently altered through various combinations of chelator (trishydroxymethylamino methane) concentration, total copper concentration, and pH.

Cellular copper content, in moles per cell, followed a hyperbolic relationship

$$\text{Cu/cell} = \frac{4.8 \times 10^{-16} a_{\text{Cu}}}{a_{\text{Cu}} + 10^{-9.2}}$$

where  $a_{\text{Cu}}$  is the free cupric ion activity. The above relationship suggests a reversible binding of copper to a single set of cellular ligand sites having a total binding capacity of  $4.8 \times 10^{-16}$  moles per cell and an association constant for reaction with copper of  $10^{9.2}$ . For *T. pseudonana* (clone 3H) copper was inhibitory at pCu values below 10.7 (i.e. cupric ion activities above  $10^{-10.7}$ ) with total growth rate inhibition occurring at pCu values below 8.3. The relationship between growth rate inhibition and cupric ion activity was not a simple hyperbolic relationship as was observed in the case of copper uptake. For an estuarine green alga *Nannochloris atomus* (clone GSB Nanno) and an open ocean strain of *T. pseudonana* (clone 13-1) partial growth rate inhibition occurred in the pCu ranges 10.3 to 8.4 and approximately 10 to 8, respectively.

Comparison of these growth inhibitory pCu levels with a calculated estimate of the pCu of seawater of pH 8.2 containing a typical total copper concentration of  $0.012 \mu\text{M}$  and having no significant copper chelation, indicates that natural cupric ion activity levels in seawater may be inhibitory to these three clones.

Evidence was found for the complexation of copper by extracellular products of the alga *T. pseudonana* (clone 3H). Cupric ion selective electrode measurements of copper complexation in unused low salinity culture media and in identical media in which algae had been grown and from which they were subsequently filtered showed a higher degree of copper complexation in the used media. Parallel studies of copper toxicity and cellular copper uptake in an unused medium and in a culture filtrate demonstrated a lower copper toxicity and a decreased cellular copper uptake in the used medium.

Cupric ion-selective electrode measurements and bioassay experiments support the hypothesis that copper is complexed by organic ligands in at least some natural waters. Copper added to filtered untreated river water is more highly complexed than that added to river water that has been uv irradiated to remove some portion of the dissolved organic matter. Copper toxicity to *N. atomus* is significantly increased in seawater from Vineyard Sound and in salt marsh water subjected to prior ultraviolet irradiation.

Supported by: *W.H.O.I. Fellowship and an NSF Grant GB-33288.*

#### THE TANGENTIAL DRAG OF AN AXIALLY OSCILLATING CYLINDER

Susan Schultz Tapscott

An experimental investigation of the tangential drag of an axially oscillating cylinder is presented. Deep-sea mooring cables are oscillated sinusoidally at ocean wave amplitudes and frequencies, and experimental values of the tangential (friction) drag coefficient are obtained. The experimental values of the drag coefficient are



compared with values predicted by the exact solution to the Navier-Stokes equations for a smooth cylinder in laminar flow. The experimental data reports drag coefficient values that are consistently higher than those predicted by the laminar theory. An attempt is made to interpret the discrepancies in terms of the effects of roughness and/or turbulence.

Supported by: *W.H.O.I. Fellowship.*

*STRUCTURAL EVALUATION OF FIXED OFFSHORE PLATFORMS*

J. Kim Vandiver

In fixed offshore structures, damage incurred below the waterline is often difficult to detect, but significant enough to be the source of a subsequent massive failure. A technique is described that can be used to detect subsurface structural failure by detecting changes in the natural frequencies of the structure. One tower was extensively studied; the dynamic measurement and analysis techniques are described. A parallel computer model of this tower was used to simulate the effect of removal of structural members on natural frequency. The parameters which determine the level of minimum detectable damage are discussed.

Experimental data correlating wind and wave height spectra to observed structure response is presented. Statistical Energy Analysis is introduced as a method for predicting the dynamic response of offshore towers to random waves. The method is superior to the classical random vibration approach, in that it does not require the calculation of the wave force spectrum from the wave height spectrum, thus eliminating the calculations and assumptions common to the frequently used Morrison wave force equation. SEA is also applicable to a broad range of fixed and floating structures.

Supported by: *W.H.O.I./M.I.T. Joint Program in Ocean Engineering and by the American Bureau of Shipping.*

*AN OCEANIC CALCIUM PROBLEM?*

George T. F. Wong  
(See C-15 for abstract)

*THE DETERMINATION OF IODIDE IN SEA WATER BY NEUTRON ACTIVATION ANALYSIS*

George T. F. Wong

A simple and sensitive method for the determination of iodide in sea water by neutron activation analysis has been developed. Iodide is separated from most other anions by passing sea water through a strongly basic anion-exchange column, recovered by elution with 2M sodium nitrate, and concentrated from the eluate by precipitation as palladium (II) iodide in the presence of excess of palladium (II) with elemental palladium as carrier; elemental palladium is generated by reduction

of some of the palladium (II) with thiosulfate. The precipitate is separated from the supernatant liquid by filtration. Checks on the efficiency of separation by means of added  $^{125}\text{I}$  showed recoveries of  $100 \pm 3\%$ . The filter paper containing the precipitate is pressed into a pellet for neutron activation analysis by irradiation for 5 min at a flux of  $4 \cdot 10^{12} \text{ n cm}^{-2} \text{ s}^{-1}$  and counting the  $^{128}\text{I}$  442.7-ke V photopeak.

Supported by: *W.H.O.I. Fellowship and an NSF Grant DES74-22292.*

*THE DISTRIBUTION OF IODINE IN THE UPPER LAYERS  
OF THE EQUATORIAL ATLANTIC*

George T. F. Wong

Thirty-seven stations were occupied during five transects between  $2^{\circ}\text{N}$  and  $2^{\circ}\text{S}$  along  $33^{\circ}\text{W}$ ,  $28^{\circ}\text{W}$ ,  $22^{\circ}\text{W}$ ,  $16^{\circ}\text{W}$  and  $10^{\circ}\text{W}$ . Samples from the surface layers were analyzed for iodate. Some selected samples were analyzed for iodide. Iodate is depleted in the surface waters as reported in earlier papers. The depletion is more pronounced than in the Argentine Basin and possibly reflects the higher productivity in the equatorial area. Superimposed on this feature, sharp iodate maxima of a few tens of meters thick were observed. These maxima form a continuous lens across the Atlantic. Along the equator, the lens occurs at 80 m at  $33^{\circ}\text{W}$  and rises upwards to 55 m at  $10^{\circ}\text{W}$ . This lens coincides with a core of high salinity water which is characteristic of the Equatorial Undercurrent. Longitudinal sections reflect the complexity of the equatorial current system. Based on the iodate concentration, oxygen content, salinity, current velocity and direction, at least three cores of water with high iodate concentrations can be identified. The sources of these water types are unclear. Some speculations are made on the basis of our present knowledge of the currents and the productivity of the Equatorial Atlantic.

Supported by: *W.H.O.I. Fellowship and an NSF Grant DES74-22292.*

*THE MARINE CHEMISTRY OF IODINE IN ANOXIC BASINS*

George T. F. Wong

We have determined dissolved  $\text{IO}_3^-$  and  $\text{I}^-$  concentrations in two anoxic basins, the Black Sea and the Cariaco Trench, together with data from the Venezuela basin which serves as a comparison for normal oceanic conditions. In open oceans,  $\text{IO}_3^-$  is the predominant species; its concentration is lowest at the surface ( $\sim 0.3 \mu\text{M}$ ) and increases with depth ( $0.5 \mu\text{M}$ ). In contrast the  $\text{I}^-$  concentration shows maximum values in surface waters and rapidly decreases to  $< 0.01 \mu\text{M}$  at depth. In anoxic basins the reduced pE reverses this trend. The concentration of  $\text{I}^-$  increases rapidly above the oxygen-sulfide interface from  $0.03 \mu\text{M}$  to  $0.24 \mu\text{M}$  in the Cariaco Trench and the Black Sea respectively. The  $\text{IO}_3^-$  concentration, meanwhile, decreases to zero. The total iodine to salinity ratio is lower in the surface waters with a range of 7.6 to 12.3 n moles suggesting a possible depletion by organisms. In the anoxic basins, a g maximum is observed just above the oxygen-sulfide interface (15 to 17 n moles and is indicative of particle dissolution in a strong pycnocline.

It is constant at 12.6  $\mu$  moles in the anoxic zone of the Cariaco Trench, whereas, in the Black Sea, it  $\mu$  increases with depth from 10.3 to 19.6  $\mu$  moles and suggests a possible flux of iodide from the bottom sediments. By  $\mu$  considering the distribution of iodate and iodide in oxic and anoxic basins and our present analytical capability, the lower limit of the pE of the oceans is estimated to be 10.7. Thermodynamic considerations further suggest that the iodide-iodate couple is a poor indicator for the pE of the oceans with a limited usable range of 10.0 to 10.7.

Supported by: *W.H.O.I. Fellowship and an NSF Grant DES-22292.*

*FLOW AND SEDIMENT PROPERTIES INFLUENCING  
EROSION OF FINE-GRAINED MARINE SEDIMENTS:  
SEA FLOOR AND LABORATORY EXPERIMENTS*

Robert Alexander Young

Erosion processes involving fine-grained marine sediments were studied by using an *in situ* flume to erode undisturbed bottom sediments on the sea floor in Buzzards Bay, a shallow marine embayment off the Massachusetts coast. The muddy sea floor in that area is characterized by a deposit-feeding infauna that reworks the sediments.

Observations made with the *in situ* flume suggest that erosion resistance of compacted bottom sediments is up to twice as great as the erosion resistance of biogenically reworked sediments. Estimates of erosional bed shear stress from the *in situ* flume experiments are similar to estimates made during this study of bed shear stress developed in near-bottom tidal currents. It is inferred that erosion by *in situ* flume produces reasonable estimates of bed shear stress necessary to erode undisturbed bottom sediments on the sea floor.

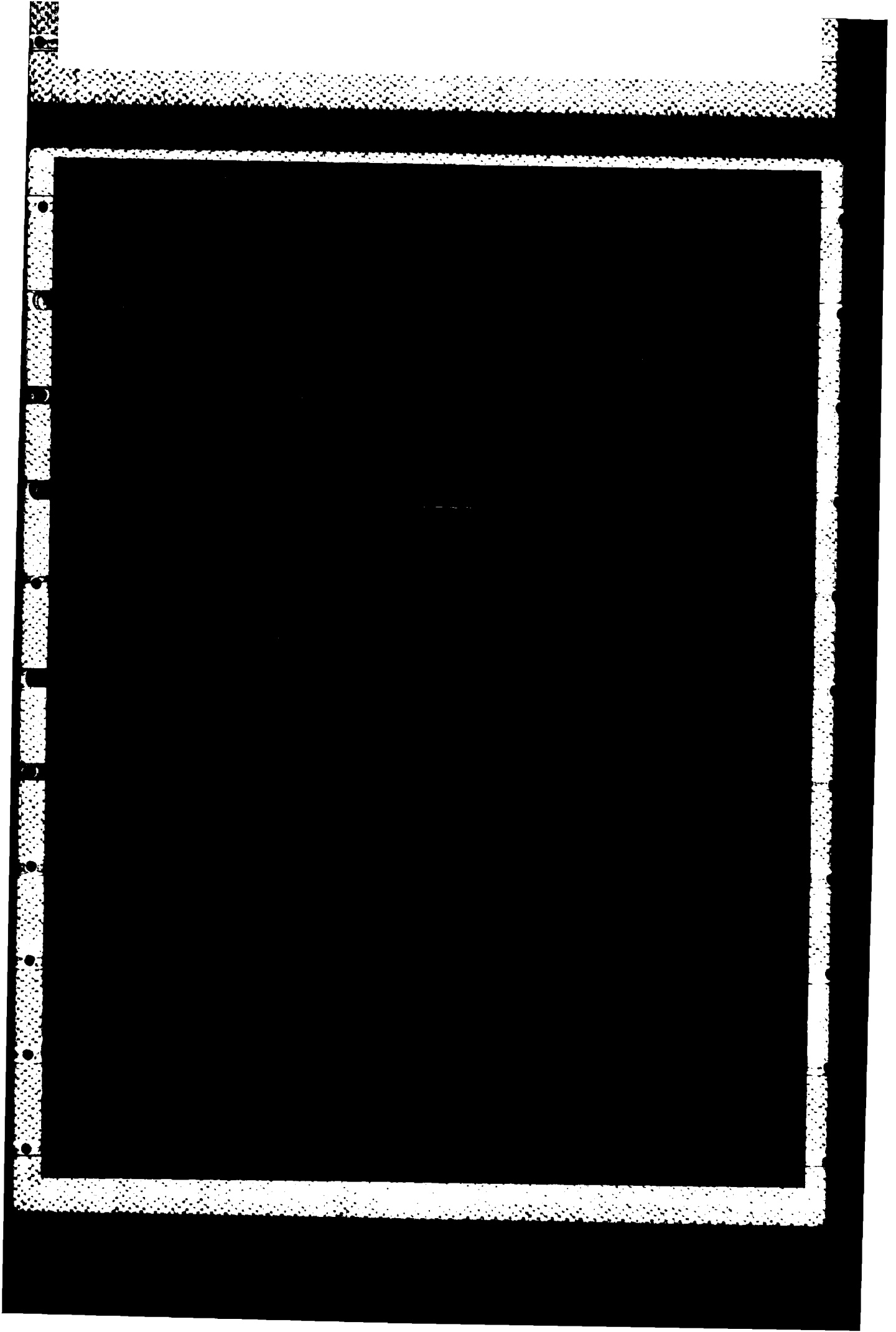
Buzzards Bay muds were redeposited in a laboratory flume and eroded after various periods of reworking by the deposit-feeding organisms contained in them. Other Buzzards Bay mud samples were treated to remove organic matter, and the erosion resistance of flat beds of these sediments was also investigated in a laboratory flume.

The surface of a biogenically reworked bed after two months was covered with mounds, burrows, trails, and aggregates composed of sediments and organic material. This bed was similar in appearance to many of the beds eroded by the *in situ* flume. The two month bed eroded at an erosional shear stress similar to the erosional shear stress necessary to erode the *in situ* Buzzards Bay muds (0.8 dynes/cm<sup>2</sup>). Beds biogenically reworked for shorter periods had high values of erosional shear stress, up to twice that of the two month bed.

The bed shear stress necessary to erode flat beds of Buzzards Bay sediments increased as the concentration of organic matter in the sediments increased. Deposit-feeders were absent in these beds, and the mode of deposition was kept uniform, so the increase of erosion resistance with increase in organic content is considered a reliable indication of sediment behavior, and not an artifact of experimental conditions.

During the *in situ* experiments, lee drifts were created behind resistant roughness elements on the sea floor. A brief study of lee drift formation in the laboratory suggests that the formation of lee drifts from fine-grained sediments can be predicted to take place when the body Reynolds number of the resistant roughness elements is below a critical value.

Supported by: *An Ocean Industries Program Grant to Dr. David A. Ross of W.H.O.I.*



MP-1

MARINE POLICY  
and  
OCEAN MANAGEMENT

1. *ATLANTIC OFFSHORE OIL: THE NEED FOR PLANNING AND REGULATION*,  
*Oceanus*, Fall, 1975, Vol.19, No.1.

James M. Friedman

An analysis of the general political and legal framework in which offshore oil development takes place. Emphasis is placed upon problems in federal-state relations and upon weaknesses in current planning and regulatory practices.

2. *HEARINGS BEFORE THE AD HOC SELECT COMMITTEE ON THE OUTER CONTINENTAL SHELF*; *House of Representatives, 94th Congress, first Session H.R. 6218*.

This statement, which was presented as expert testimony on pending legislative reforms of the federal offshore oil program, made the following points: There is lack of proper planning for offshore oil development. To remedy this problem the Interior Department must make more information available to the states. Enforcement of regulations is weak. Strict liability for oil spills is justified. Current leasing procedures encourage violation of the antitrust laws.

Supported by: *Woods Hole Oceanographic Institution and Office of Sea Grant, Department of Commerce Grant No. 04-6-158-44016*.

(1) *CHILE'S INTEREST IN THE OCEANS*

Victor A. Gallardo

The paper deals with the main aspects to be considered in the determination of Chile's national interest in the oceans. The treatment falls within the framework of marine geography or that of marine affairs as recently developed in the United States. Chile's marine orientation is here seen through the application of a generalized model, that was proposed by L. Alexander of the University of Rhode Island, which contains five major components: accessibility, investment, dependence, perception and control.

(2) *HACIA UNA POLITICA DE ADMINISTRACION DE LA ZONE COSTERA DE CHILE*

The problems arising from the multiple use of the coastal zone, the coastal seas and its resources in Chile is brought forward. The peculiarities of the country's relationship with these areas is emphasized and attention is centered over the need for Chile of a national coastal zone management policy in order to minimize present conflicts, avoid others and maximize long-term benefits from Chile's increasing use of its coastal zone.

(3) *INFORME SOBRE E TALLER/SEMINARIO ORGANIZADO POR EL PROGRAMA DE ANALISIS DE ECOSISTEMAS MARINOS, DE LOS LABORATORIOS DE INVESTIGACION AMBIENTAL, DE LA ADMINISTRACION NACIONAL OCEANICA Y ATMOSFERICA DEL DEPARTAMENTO DE COMERCIO DE LOS ESTADOS UNIDOS DE NORTEAMERICA, BOULDER, COLORADO, 1975, SOBRE EL DERRAME DE PETROLEO DEL VLCC METULA EN EL ESTRECHO DE MAGALLANES, CHILE.*

This is a report on the MESA/NOAA Seminar on the VLCC METULA oil spill in the Straits of Magellan, which seeked:

- 1) To review the results of reconnaissance surveys of the spill in the Strait of Magellan,
- 2) To review the recommendations of the reconnaissance team for further research, and
- 3) To identify alternative institutional and funding arrangements to support such research.

The paper merely pretends to transfer the results of the seminar to the Chilean scientific community which might become thus involved in bilateral cooperative scientific efforts around the problem of effects and fates of the oil spilled in the Straits.

(4) *CONSIDERACIONES PRELIMINARES EN TORNO AL  
DERRAME CAUSADO POR EL VARAMIENTO DEL BUQUE TANQUE VLCC METULA EN EL ESTRECHO DE  
MAGALLANES, CHILE.*

This is an analysis of existing data on the Metula oil spill up to March of 1975. Ecological, economic and marine policy factors are brought into play to suggest that Chile's best national interest could be further served by launching a cleaning up operation, due compensation for the ecological damage, and scientific research and monitoring on the effects and fates of the hydrocarbons spilled in the straits.

Supported by: *Woods Hole Oceanographic Institution.*

*THE VIEW FROM NEW BEDFORD*

Susan B. Peterson

The U.N. Law of the Sea negotiations, legislation to extend the U.S. fishing zone, and ICNAF (International Commission for the Northwest Atlantic Fisheries) are seen by New England's coastal fishermen as potential sources of change in fishing activities. They fear that stocks of fish are being depleted, and feel that the United States should have control over its coastal stocks. In the meantime, few New Englanders feel they can make investments in an industry that, without strong management, could soon disappear.

Supported by: *Office of Sea Grant, Department of Commerce, Grant No.  
04-6-158-44016.*

*THE PUBLIC ORDER OF OCEAN RESOURCES:  
A CRITIQUE OF THE CONTEMPORARY LAW OF THE SEA*

Dr. P. Sreenivasa Rao

Until recently, the ocean space and its resources were regarded as inexhaustible. Based on this assumption, traditional maritime law allowed each participant on the high seas to engage in accepted activities without undue interference from others.

However, contemporary realities made the earlier assumption invalid. It is now increasingly realized that there are limits to the extent to which the resources of the sea could be exploited. Fishery stocks, with respect to certain species, have been, and could be, overexploited. Problems of economic recoverability closely influence the availability of nonliving resources from the sea. With the growth of offshore petroleum drilling activities and increased volume of traffic at sea, risk of collision at sea is now an important concern for coastal zone management. Further, marine pollution due to oil and waste disposal can no longer be ignored if critical components of the ocean ecosystem are to be protected.

The changing realities have made it imperative to change the structure of the traditional law of the sea. However, modernization of maritime law, which is the principal theme of the Third Law of the Sea Conference at Caracas, Venezuela, does not come easily. It is fraught with a clash of divergent interests and opposing claims. In the contemporary debate on law of the sea, conflicting claims have been advanced to touch every aspect of the traditional as well as the projected uses of the oceans. These claims relate to:



- a. The extent of territorial waters;
- b. The extent of the continental shelf;
- c. Exploitation and conservation of living resources of the sea;
- d. Permissibility of military uses at sea;
- e. Management of marine pollution; and
- f. Preservation of freedoms of the sea.

Each of these claims gives rise to several subclaims, and they are generally inter-related.

The present study concerns the problems relating to marine mineral resource exploitation - the limits of continental shelf regime, the law of mineral resources in maritime areas beyond the limits of continental shelf, and the accommodation of mineral resource use with other competing uses of the sea.

The first chapter explores different interests that underlie the divergent claims. As these interests are closely affected by various social factors, the chapter describes the participants, their objectives, situational features attendant upon mineral resource use, availability of base values (or capabilities), strategies employed to achieve desired objectives, expected outcomes, and overriding conditional factors. In addition, the first chapter refers to the various claims arising out of the process of marine mineral resource use and the decision-making system available to resolve these claims. Before proceeding to examine trends in decision relevant to claims, the second chapter deals with a set of preferred policies. Such a clarification of policy, it is hoped, would provide a basis for appraising the trends in decision and for choosing, in the end, alternatives that would best promote common interests. The third chapter examines various claims about the extent of the continental shelf; these claims, which relate to access to deep ocean areas, are considered in the fourth chapter. The fifth chapter concerns the accommodation of mineral resource interests with several interests other than security interests. Examination of security interests is reserved for consideration in the sixth chapter. The last chapter discusses probable future trends in decision and articulates alternatives, where appropriate, to achieve common interests through the process of marine mineral resource use.

The framework of the study thus outlined follows a policy-oriented approach originally formulated by Professors Myres S. McDougal and Harold D. Lasswell of the Yale Law School in analyzing contemporary legal problems. Further, the study is adapted and enlarged from the doctoral dissertation the author presented to the Yale Law School in 1970 under the title "Offshore Natural Resources Exploitation and the World Public Order".

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#### *INSTITUTIONAL LAG IN FISHERIES MANAGEMENT*

Courtland L. Smith

For Pacific salmon and halibut fisheries the effectiveness of management institutions is evaluated against management goals using time series regression analysis. Comparing this with changes through time in fishers' behaviors indicated a process in which the effectiveness of management institutions was found to lag behind the innovativeness of fishers.

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*EVOLUTION OF THE PACIFIC CANNED SALMON FISHERY*

Courtland L. Smith

The evolution of the Columbia River salmon industry is described and related to other Pacific salmon producing areas. A variety of social, economic, and political factors led to changes in the relations between salmon producers, processors, and consumers. There was reaching outward into the ocean to harvest immature salmon, redistribution of the salmon harvest to trollers and recreational fishers, greater dependence on hatchery-built runs as the river served other uses, and the loss of the economic position of canned salmon as it was increasingly sold fresh and frozen to recreational, tourist, and luxury consumers. Unsuccessful attempts were made to stabilize the industry, but canned salmon lost its priority as a subsistence resource.

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*INTRACULTURAL VARIATION:  
DECLINE AND DIVERSITY IN NORTH PACIFIC FISHERIES*

Courtland L. Smith

Measures other than central tendency are required to develop theories of intracultural diversity. To measure the distribution of wealth, behavior, or ideas in a population, statistical measures of variation can be used. Equity and diversity measures for the distribution of wealth are proposed using the skew and kurtosis statistics. Historical data for four North Pacific fisheries indicate that associated with resource decline is greater inequity and less diversity in the distribution of fish harvested and income to fishermen and fish processors.

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*OBSERVED AND PERCEIVED IMPACTS OF DISTANT WATER FISHING:  
OREGON OTTER TRAWL CASE*

Courtland L. Smith

Distant-water fleets appeared off the Oregon coast in 1965. Change in the growth, equity, and diversity of Oregon otter trawl landings between 1965 and 1972 indicated that the observed well-being of otter trawl fishermen did not change significantly. Fishermen, however, perceived the foreign competition as a significant threat to their industry.

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*FISHERIES REGULATION: VARIATIONS ON A THEME*

Leah J. Smith and Susan B. Peterson

The history and present status of fisheries regulation in the United States are reviewed. Different methods of managing fisheries are described, with examples from the United States and other countries. Regulation through limited entry is suggested as a possible method of bringing the economic and social aspects of the fishery into management.

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*THE ECONOMICS OF WASTE WATER-AQUACULTURE SYSTEMS*

Leah J. Smith and John E. Huguenin

Due to recent environmental legislation and growing scarcities of popular seafoods, there is considerable interest in innovative systems that can strip nutrients biologically from waste water and produce potentially useful materials. While many variations of such systems exist, the systems described here are based on the secondary sewage-marine aquaculture system developed at the Woods Hole Oceanographic Institution with an option of using thermal effluent as a heat source. The design, performance and resulting costs of operational systems for commercial production scaled up by factors of 10, 100 and 1,000 are projected and compared. The largest of these systems would be able to handle the waste water from a city of 100,000 people. Despite uncertainties in the systems, our analysis shows that large-scale systems using sewage as a nutrient source and free heat from power plant effluent (or located in a warm climate) could be profitable.

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*TECHNOLOGICAL TRANSFER IN MARINE SCIENCE*

Leah J. Smith and David A. Ross  
(see GG-35 for abstract)

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