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SUBMITTED IN 1979 FOR PUBLICATION

WOODS HOLE OCEANOGRAPHIC INSTITUTION

Woods Hole, Massachusetts

Editor: Shelley M. Lauzon

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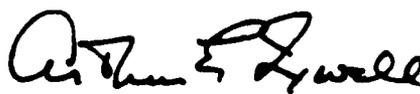
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PREFACE

This Summary of Abstracts contains all abstracts submitted for publication during calendar year 1979 by the staff and students of the Woods Hole Oceanographic Institution. Because some of the abstracts may not be published in the journal to which they have been submitted initially, we have purposely omitted identifying the journals. The volume is intended to be informative, but not a bibliography.

The abstracts are listed by title in the Table of Contents and are grouped into one of our five departments, marine policy, or the student category. An author index is presented in the back to facilitate locating specific papers.



Arthur E. Maxwell



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# BIOLOGY

B-1

DEPARTMENT OF BIOLOGY  
George D. Grice, Department Chairman

## A Q U A C U L T U R E

THE EFFECT OF LOW-PROTEIN FEEDS ON THE  
BIOENERGETICS OF JUVENILE LOBSTERS  
(HOMARUS AMERICANUS MILNE EDWARDS)

Judith M. Capuzzo

The bioenergetics of juvenile lobsters fed a brine shrimp (*Artemia salina*) diet were compared with the bioenergetics of lobsters fed three formulated feeds; the formulated feeds were pelletized shrimp meal based feeds, varying in both protein content (16.7-23.3%) and carbohydrate content (22.9-31.3%) and the protein:carbohydrate ratio (0.5-1.0). The best growth was measured among lobsters fed the brine shrimp diet and the 23.3% protein feed with no significant difference occurring between the two groups. Lobsters fed the two lower protein feeds (16.7% and 20.0%) had significantly lower growth rates equivalent to  $\approx$  80% of that of the two other groups. The protein efficiency ratios of all groups of lobsters, however, were inversely related to the protein level of each feed.

All feeds were assimilated at the same level ( $\approx$  90%) but there were significant differences in food consumption rates, respiration rates and ammonia excretion rates among lobsters from the four experimental groups. The O:N ratios measured in the four experimental groups were inversely related to the protein level of the four feeds, indicating an increased dependence on carbohydrate catabolism for energy production with low dietary protein levels. The reduced growth rates of lobsters fed the two lower protein feeds were a result of differences in food consumption rates and not increased energy expenditures or reduced assimilation efficiencies associated with these feeds. The protein sparing action of carbohydrates in formulated feeds for the American lobster and the relationship of protein:carbohydrate ratios and protein utilization in the lobster is discussed.

Presented at: ICES Statutory Meeting,  
Warsaw, Poland.

Supported by: NOAA, Office of Sea Grant  
Grant No. 04-7-158-44104.

PRIMARY PRODUCTION OF SOME FRESHWATER  
MACROPHYTES: SEASONAL CYCLE AND  
DENSITY EFFECTS

Tom A. Debusk, M. Dennis Hanisak,  
LaVergne D. Williams and John H. Ryther

Three species of freshwater macrophytes, *Lemna minor* (duckweed), *Eichhornia crassipes* (water hyacinth) and *Hydrilla verticillata*, were grown in artificial culture units in Fort Pierce, Florida. *Lemna* and *Eichhornia* were routinely harvested back to a constant starting density. *Hydrilla* was not harvested, but its biomass allowed to accumulate in the cultures.

After determination of optimal environmental growing conditions with respect to composition and concentration of nutrient enrichment medium, water exchange rate and biomass density (of the harvested species), annual yields were determined. These averaged 3.7, 24.2 and 4.2 g dry wt/m<sup>2</sup>.day (13.5, 88.3 and 15.3 dry metric tons/ha year) for the *Lemna*, *Eichhornia* and *Hydrilla* respectively. Yields of *Lemna*, *Eichhornia* and *Hydrilla* were strongly dependent on culture density and were approximately three times greater than monitored yields of natural populations in nearby eutrophic environments.

In Press: Aquatic Botany.

Supported by: U.S. Department of Energy  
Contract #EY-76-S-02-2948.

RECYCLING THE NUTRIENTS IN RESIDUES FROM  
METHANE DIGESTERS OF AQUATIC MACROPHYTES  
FOR NEW BIOMASS PRODUCTION

M. Dennis Hanisak, LaVergne D. Williams  
and John H. Ryther

The floating freshwater macrophyte *Eichhornia crassipes* (water hyacinth) and the red seaweed *Gracilaria tikvahiae* were fermented in anaerobic digesters, producing 0.4 and 0.2-0.4 l/g ash-free dry weight of gas containing 60% methane with conversion efficiencies of 46% and 23-46% respectively. *Eichhornia* and *Gracilaria* grown in cultures using their respective digester residues as a nutrient source produced 4 and 3 times respectively the organic yields of cultures grown in defined chemical enrichment media.

Of 255 g of water hyacinth-nitrogen loaded into the digester, 123 g (48%) were recovered in the liquid digester residue of

which 80% (65%) were reassimilated by the hyacinths, an over-all efficiency of 31%.

Supported by: U.S. Department of Energy  
Contract #EY-76-S-02-2948.

THE EFFECTS OF NITROGEN AND SEAWATER  
FLOW RATE ON THE GROWTH AND BIOCHEMICAL  
COMPOSITION OF GRACILARIA FOLIIFERA VAR.  
ANGUSTISSIMA IN MASS OUTDOOR CULTURES

Brian E. LaPointe and John H. Ryther

The effects of nitrogen species ( $\text{NH}_4^+\text{-N}$  and  $\text{NO}_3^-\text{-N}$ ), loading (m moles of N/day) and seawater flow rate on the growth of the red seaweed *Gracilaria foliifera* var. *angustissima* (Harvey) Taylor were investigated in outdoor culture tanks. In one experiment, cultures received seawater enriched with either  $\text{NH}_4^+$ ,  $\text{NO}_3^-$  or secondarily treated wastewater (with N as  $\text{NO}_3^-$ ) but the same daily nitrogen load at four seawater turnover rates (1, 7.5, 15 and 30 culture volume exchanges/day). In another experiment, cultures were maintained at four turnover rates (1, 7.5, 15 and 30 culture volume exchanges/day) with  $\text{NH}_4^+$  or  $\text{NO}_3^-$  at a given concentration so that nitrogen loading was proportional to turnover rate.

Below 15 m moles of N/day, algal growth was N - limited and the plants had high C/N values and appeared bleached; above 15 m moles/day, the plants had C/N values of  $< 10$  and were a dark brown color. Above this minimal daily N loading, algal growth was highly dependant upon flow rate *per se*. Yield of *Gracilaria* was greater with  $\text{NH}_4^+$  than  $\text{NO}_3^-$  at nitrogen loadings just adequate to support exponential growth; however, at higher levels of nitrogen loading the maximum recorded yields (up to 44 g dry weight/ $\text{m}^2 \text{ day}^{-1}$ ) occurred with  $\text{NO}_3^-$  rather than  $\text{NH}_4^+$ .

Water, ash and caloric content of *Gracilaria* was positively correlated with C/N values in N - limited plants. Absolute levels of both phycoerythrin and chlorophyll increased proportionally with decreasing C/N values of the plants. Thus the observed nitrogen-related pigment changes in *Gracilaria* are light intensity and not necessarily light quality adaptations.

In Press: Botanica Marina.

Supported by: U.S. Energy Research and  
Development Administration Contract  
#E(11-1) 2948.

TRACE CONTAMINANT ACCUMULATION BY  
ORGANISMS GROWN IN A WASTE RECYCLING  
AQUACULTURE SYSTEM

Roger Mann and John H. Ryther

Three species of bivalve mollusc *Crassostrea gigas* (Thunberg), *Ostrea edulis* L., *Tapes philippinarum* (Adams and Reeve, 1850), one species of crustacean, *Homarus americanus*, and one species of macroscopic algae *Gracilariopsis sjostedtii* were grown in a pilot-scale marine waste recycling aquaculture system for a period of 18 months. Organisms were exposed to 14 different regimes of food chain enrichment using either secondary treated sewage effluent, a mixture of inorganic nitrogen and phosphorus compounds free of contaminants, or a combination of both to simulate "growth" and "deuration" periods in an on-site application. Throughout the study organisms were sacrificed at monthly intervals and assayed for seven trace metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn). Sewage effluent used for food chain enrichment was assayed for the same suite of metals three times per week. No significant differences were evident between organisms cultured in the contaminant-free and effluent enriched regimes. Shellfish trace metal contents were consistently below F.D.A. "alert" levels. *H. americanus* trace metal levels were within acceptable standards for human consumption. Trace metal levels in *G. sjostedtii* were comparable with those recorded for natural populations of macrophytes. Data suggest that trace metals constitute a minimal public health problem in organisms cultured for human consumption in waste recycling systems, however problems related to organic residues and viruses have yet to be fully evaluated.

In Press: Proc. 10th Annual Meeting  
World Mariculture Society,  
Honolulu, HI, January 22-26, 1979.

Supported by: Sarah Scaife Foundation.

TREATED SEWAGE EFFLUENT AS A NUTRIENT  
SOURCE FOR MARINE POLYLCULTURE

John H. Ryther

Pilot-scale experiments are described in which treated sewage effluent is used as a nutrient source for a marine polyculture system consisting of unicellular algae, bivalve molluscs, lobsters, fin-fishes, and red seaweeds.

In Press: Proc. Seminar and workshop on aquaculture systems for wastewater treatment. Davis, CA, Sept. 11-12, 1979.

Supported by: National Science Foundation - RANN GI-32140.

#### GROWTH AND YIELD OF AQUATIC PLANTS

John H. Ryther

The distinction is made between plant productivity or yield (organic matter produced per unit of area and time) and specific growth rate (organic matter increase per unit of plant biomass and time). The two are related, since yield is the product of growth rate and plant density per unit area, but the relationship is not constant because growth rate is itself a function of plant density. This is illustrated for four different kinds of aquatic plants, marine diatoms, a seaweed (Gracilaria tikvahiae) and two freshwater macrophytes (Lemna minor and Eichhornia crassipes). The point is made that greatly exaggerated yield projections may result from using independently derived growth rate and density values.

Supported by: SERI XR-9-8133-1.

#### FRESHWATER MACROPHYTES FOR ENERGY AND WASTEWATER TREATMENT

John H. Ryther, Thomas A. DeBusk, M. Dennis Hanisak and LaVergne D. Williams

Freshwater weed crops are capable of simultaneously providing advanced treatment (nutrient removal) of wastewater passed through them and producing biomass that may be converted to fuel by anaerobic digestion. Performance of both functions depends upon the rate of primary organic production of the plant species in question.

Annual yields of the floating species Lemna minor (duckweed) and Eichhornia crassipes (water hyacinth) and of the submerged species Hydrilla verticillata were determined in central Florida. Yields of duckweed and Hydrilla, 13.5 and 15.3 m tons/ha·year respectively, are comparable to many temperate terrestrial food and grass crops. The yield of water hyacinths, 88.3 m tons/ha·year, is among the highest documented for any plant species on earth.

A one thousand hectare water hyacinth farm is capable of producing  $10^{12}$  BTU of energy per year as methane gas and, at the

same time, of removing the nutrients from the wastewater of a population of 700,000 people.

In Press: Proc. National Symp. Wetlands.

Supported by: U.S. Department of Energy Contract #EY-76-S-02-2948.

#### BIOMASS PRODUCTION BY MARINE AND FRESHWATER PLANTS

John H. Ryther, LaVergne D. Williams, M. Dennis Hanisak, Richard W. Stenberg and Thomas A. DeBusk

Studies were continued during 1977-78 on the growth and yields in culture of the red seaweed Gracilaria tikvahiae. Partial control of epiphytes was achieved by nutrient removal, shading, and/or biological agents. For the first time, a single clone of the alga was grown continuously throughout the year without replacement. Yields in large (2600 liter) aluminum tanks averaged 21.4 g dry wt/m<sup>2</sup>·day, equivalent to 31 tons/acre·year.

Yields of the freshwater macrophytes Lemna minor (common duckweed), Eichhornia crassipes (water hyacinth), and Hydrilla verticillata have also now been measured throughout the year with mean yields of 3.7, 24.2 and 4.2 g dry wt/m<sup>2</sup>·day (5.4, 35.3 and 6.1 dry tons/acre·year) respectively. Yields of duckweed and water hyacinths in the cultured units have averaged roughly three times those of the same species growing in highly eutrophic natural environments.

Presented at: 3rd Annual Biomass Energy Systems Conference Proc. SERI/TP-33-286, Oct., 1979. pp. 13-23.

Supported by: U.S. Department of Energy Contract #EY-76-S-02-2948 and the Harbor Branch Foundation, Inc.

#### METHANE FERMENTATION OF AQUATIC BIOMASS

D. L. Wise, D. C. Augenstein, and J. H. Ryther

Four aquatic biomass species were anaerobically fermented to methane as part of an evaluation of these biomass as potential energy resources. Two freshwater weeds (Duckweed (Lemna sp.) and Hydrilla verticillata) and two marine algae (Gracilaria ceae and Ulva lactuca) were evaluated. Volatile solids, ash content,

calorific values, and elemental analyses are reported for these biomass. All four were fermented at mesophilic (37°C) conditions in 50 l CSTR units using a rich nutrient feed of essentially equal parts by weight sewage sludge and aquatic biomass in an approximately 5% solids concentration slurry and with a 26-day retention time. In addition, the two freshwater weeds were evaluated in a similar manner at thermophilic (60°C) conditions. Bioconversion efficiency was based on measured energy out, as methane, and measured energy in, as calorific values of the biomass. It was found that 25 to 34% of the energy value in the freshwater weeds was recovered at mesophilic conditions, a low value perhaps due to the fact that steady-state conditions were not reached in the fermenters. For the marine species, 27 to 45% of the energy value was recovered under the same conditions. Conversion of the freshwater weeds at thermophilic conditions, however, was from 23 to 46%. It was found that by assuming all total volatile solids in the seaweed had an oxidation state equivalent to cellulose the same bioconversion efficiency was obtained as measured directly, appearing to indicate a high fraction of biodegradable polysaccharides. Freshwater weeds, however, demonstrated a much lower conversion based on calorimetric values than with the assumption that all volatile material was cellulosic in nature. This may indicate that bioconversion of a cellulosic fraction occurred, but that residual higher energy components in the biomass such as lignin were nonbiodegradable under these conditions. Results of the bioconversion of alkaline pretreated (saturated lime) Duckweed were approximately equal to those with the untreated biomass. An inhibition investigation to explain lower than anticipated bioconversion was conducted on the two marine species based on their high degree of sulfonation of polysaccharides. This hypothesis proved to be invalid, and slow acclimatization of inoculating microorganisms was given as a possible explanation of observed results. Further, in situ or batch fermentation were carried out at mesophilic conditions using minimal inoculum. Both freshwater aquatic biomass were evaluated in 2l units, while *Hydrilla* was also evaluated in a 50 l unit. It was found that 80% of the methane was evolved in the first two months of operation. Moreover, bioconversion performance in these simple mesophilic in situ units were equal to that in the CSTR units of thermophilic conditions, namely 34-46% conversion. Obtaining baseline biomass conversion results in simple in situ units

appears most practical. Pretreatment alternatives and novel processing techniques which improve on conventional CSTR technology appear to be required to improve bioconversion energy efficiencies.

In Press: Resource Recovery and Conservation, Vol. 4: 217-237, 1979.

Supported by: U.S. Department of Energy Contract #EY-76-S-02-2948.

## BENTHOS

### BEHAVIOR OF LOBSTERS

Judith M. Capuzzo and William W. Reynolds

The impact of power plant discharges and entrainment on marine ecosystems has recently become an area of significant concern with the increased demand for coastal power stations. Where entrainment or discharges affect commercially important species, detrimental effects result in not only losses in natural resources but significant economic losses as well. Because of its economic importance as a principal fishery of the northeastern United States and the maritime provinces of Canada, the American lobster (*Homarus americanus* Milne Edwards) has received some attention in regard to the impact of power plants on natural populations and potential damage to the fishery. This chapter is a review of the existing data concerning the impact of power plants on natural populations of lobsters and provides a framework for future research.

In Press: Power plants: Effects on fish and shellfish behavior. Academic Press, New York

Supported by: NOAA, Office of Sea Grant Grant No. 04-7-158-44104.

### BIOGEOGRAPHY AND NATURAL HISTORY OF SPHAEROMA WALKERI STEBBING (CRUSTACEA: ISOPODA) AND ITS INTRODUCTION TO SAN DIEGO BAY, CALIFORNIA

James T. Carlton and Ernest W. Iverson

*Sphaeroma walkeri* is recorded from San Diego Bay, California, closing an Eastern Pacific gap in its distribution noted by Miller (1968). It occurs abundantly with other isopods in the warmer waters of south San Diego Bay (but is absent in nearby Mission Bay) in fouling, crevices, empty borer burrows, empty barnacle shells, and

in other habitats. The commensal isopod Iais is absent from S. walkeri in San Diego Bay, but a variety of epizoics occur on the animals.

Around the world, S. walkeri is recorded as a shallow (generally less than 5 m depth), warm-water, non-boring, fully marine thigmotactic isopod common in crevices and in fouling. Spatial and temporal patterns of its distribution suggest that rather than being a pantropical cosmopolitan species, S. walkeri is indigenous to the northern Indian Ocean. It has spread via ships to three general port systems in the Old World (Suez - Eastern Mediterranean, South Africa - Mozambique, and Australia), and to four New World port systems (Brazil, Florida - Caribbean, Hawaii, and California), all of the latter during or since World War II. Sphaeroma walkeri demonstrates the classical disjunct distributional pattern of a harbor-dwelling synanthropic marine invertebrate, and adds to the more than 150 known species of introduced invertebrates on the North American Pacific coast.

In Press: Journal of Natural History.

INTRODUCED INVERTEBRATES OF  
SAN FRANCISCO BAY

James T. Carlton

Almost 100 species of exotic marine invertebrates have been introduced into San Francisco Bay by man in the past 130 or more years. Primary mechanisms of introduction include transport of fouling, boring, and ballast-dwelling organisms by ships and epizoic and nestling invertebrates by commercial oysters. With the resolution of taxonomic problems and adequate exploration, many more introduced species may eventually be recognized from the Bay.

The impact of this exotic fauna can be assessed in economic terms (pestiferous species, including shipworms and other borers) and in geologic terms (an introduced boring isopod has modified extensive portions of the bay shoreline by weakening clay and mud banks). The greatest effect, however, may be biological and ecological: the establishment of an introduced fauna as numerical and biomass dominants in many regions of the Bay, as revealed in both short- and long-term quantitative and qualitative studies. The modern-day significance

of introduced species in fouling, benthic, and mudflat ecosystems in portions of San Francisco Bay raises questions as to the role of invertebrates prior to the mid 19th century both in the organic matter budget of the Bay-Estuary system and in the support of large native shorebird populations.

Man's extensive modifications of the Bay and concomitant creation of novel environmental conditions, the absence of a diverse native estuarine fauna, and competitive displacement have all played roles in the successful establishment of this impressively large and diverse introduced fauna.

Published in: San Francisco Bay: The Urbanized Estuary. Ed. T.J. Conomos, Pacific Division, AAAS, pp. 427-444.

Supported by: Ph.D. Thesis (in part), University of California at Davis.

IN SITU STUDIES OF DEEP-SEA COMMUNITIES

J. Frederick Grassle

Submersibles are likely to be increasingly important in studies of deep-sea benthic communities. To use the submersible efficiently future studies will be done at permanent bottom stations where geologists, chemists, biologists and physical oceanographers can cooperate to study the factors controlling the major fluxes of organic and inorganic constituents in the benthic boundary layer.

By perturbing deep-sea communities in various ways it is possible to sort out how individual life cycles of populations and interrelationships among species are related to patterns of environmental variation. The relatively constant physical regime of the deep sea makes it an excellent laboratory for studying the mechanisms by which populations are adapted to the environment and each other.

Published in: Advanced Concepts in Ocean Measurements published as a Belle Baruch Library of Marine Science Volume by U. of South Carolina Press.

Supported by: National Science Foundation Grants OCE76-21968 and OCE78-19820.

RESPONSE OF BENTHIC COMMUNITIES IN MERL  
EXPERIMENTAL ECOSYSTEMS TO LOW LEVEL,  
CHRONIC ADDITIONS OF NO. 2 FUEL OIL

J. Frederick Grassle, R. Elmgren and  
Judith P. Grassle

The macrofauna and meiofauna of three oiled and three control experimental ecosystems at the Marine Ecosystems Research Laboratory (MERL) were followed for 25 weeks of semi-continuous additions of a water accommodated fraction of #2 fuel oil. Water column hydrocarbon levels were maintained at about 190 ppb, and after 20 weeks 109 µg/g dry weight fuel oil hydrocarbons were recorded in the top 2 cm of sediment.

This simulated chronic oil pollution resulted in a highly significant decline in the number of macrofaunal and meiofaunal individuals in the experimental tanks compared with the controls. The effect was apparent on the numbers of individual macrofaunal species, and on all metazoan meiofaunal groups.

Supported by: Subcontract from the University of Rhode Island Environmental Protection Agency Grant No. R803902020.

LASTING EFFECTS OF LOW-LEVEL CHRONIC  
ADDITIONS OF NO. 2 FUEL OIL TO REPLICATED  
MARINE BENTHIC COMMUNITIES

Judith P. Grassle, J. Frederick Grassle,  
L. Susan Brown-Leger, Nancy J. Copley,  
and Jennifer G.S. Derby

Twice-weekly additions of a water-accommodated fraction of No. 2 fuel oil to large marine microcosms from March to July 1978, resulted in a highly significant decline in the number of benthic macrofaunal species and individuals in experimental tanks compared with controls. The average water column hydrocarbon levels were 93 ppb ( $\mu\text{g}\cdot\text{l}^{-1}$ ) (range 11-235 ppb). Total saturated hydrocarbons in the surface sediment reached their maximum concentration in July, shortly after the termination of oil additions, and subsequently declined sharply; but the reduction in the number of macrofaunal species and individuals in the oiled tanks persisted through December. This is the first demonstration of the effects of such low levels of hydrocarbons on replicated marine communities under controlled conditions.

Supported by: Subcontract from the University of Rhode Island Environmental Protection Agency Grant No. R803902020.

AN EXPERIMENTAL FIELD STUDY OF HERMIT  
CRAB RESOURCE UTILIZATION: QUANTIFICATION  
OF SNAIL SHELL WEAR, MOVEMENT AND  
ENCrustATION

Armand M. Kuris, James T. Carlton and  
Michael S. Brody

Empty Tegula gallina shells obtained directly from living snails were used as a naturally marked shell equivalent to the native T. funebris of Bodega Head, central California. Two species of intertidal hermit crabs, Pagurus samuelis and P. hirsutiusculus, occupying T. funebris shells were removed from their shells and given the undamaged, new T. gallina shells. In this manner 1410 T. gallina shells in mint condition were released into the rocky intertidal zone in August, 1973. Five days later an attempt at census recovered 907 shells. At monthly intervals thereafter census attempts were made until the November 1974 census when the last 14 shells were recovered and not released. Shell attrition was greatest in the first two months, remained at a plateau level of 400-500 in the winter months and then declined through the spring and summer of 1974. From February until November the decline in the number of T. gallina shells was associated with increasing deterioration of shell condition due to wear.

Lateral movement of the marked shells appeared to be restricted by surge channels and rocky outcroppings. Exchange of shells with the immediate shallow subtidal zone also appears negligible at this locality. These restrictions on resource mobility suggest that resource allocation for hermit crabs is governed by local factors on a microgeographic scale.

Ninety percent of the T. gallina shells were occupied by the behaviorally dominant species, P. samuelis from shortly after the release date until May, 1974. Thereafter the proportion of shells carried by P. samuelis steadily declined until only 36% of the shells in November, 1974 were so occupied. The decline in occupancy by this species mirrored a rise in the proportion of empty, apparently abandoned shells in the final months of the study. The subordinate crab, P. hirsutiusculus occupied 5-14% of the shells in all samples. An increased rate of occupancy to 18% in August, 1974 may have been associated with the increased unsuitability of these shells for the behavioral dominant P. samuelis.

Shell wear was evaluated by principal components analysis, shell aperture size-shell weight regression analyses and fre-

quencies of various qualitative damage categories. Shell wear vectors of principal components I and II for measurements of new, 9-month-old and 16-month-old shells measure the extent of changes in shell size (PC I) and snell shape (PC II). Shape changes with extensive wear. Typically worn shells have reduced shell length, width and weight measurements but not aperture width and length. Weight loss after nine months is considerable, averaging 29% of the original weight for small shells and 49% for large shells. The sequential pattern of shell wear is described for the first time. Recognizable damage typically begins with a perforated penultimate whorl and proceeds to the last stage of deterioration, a body whorl fragment.

Pagurization is defined as the encrustation of regions of a snail shell, occupied by a hermit crab, that are maintained free of fouling organisms by the living snail. The rate of settlement by epizoic organisms such as spirorbid polychaetes, barnacles, bryozoans and hydroids can provide an indicator for the rate of entry of newly killed snail shells into the hermit occupancy compartment of a resource utilization model.

Supported by: Bodega Marine Laboratory and University of California at Santa Barbara.

THE ECTOPARASITISM OF BOONEA AND FARGOA  
(GASTROPODA: PYRAMIDELLIDAE)

Robert Robertson and Terry Mau-Lastovicka

1. Three Boonea species (occurring in sympatric species pairs) occupy different habitats and have different molluscan host preferences. In the field, B. seminuda is preferentially with Crepidula fornicata or Argopecten irradians, B. bisuturalis with Littorina littorea (introduced), Ilyanassa obsoleta or Crassostrea virginica, and B. impressa with C. virginica. Weights of the first two species are about 0.3-0.17% those of their hosts. In the laboratory, B. seminuda was attracted much more to Crepidula fornicata than to Littorina littorea. With B. bisuturalis it was vice versa.

2. In the laboratory, B. seminuda fed on 22 out of the 36 gastropod and bivalve "hosts" offered; B. bisuturalis fed on 37 out of 45, and B. impressa fed on 36 out of 37. Some of these mollusks probably serve as secondary hosts in nature. Boonea definitely is not host-specific. Polychaetes, Chaetopleura and Molgula were not fed on.

3. Fargoa dianthophila and F. bartschi, two much rarer species, compete with each other for space and food by both obligately parasitizing species in the genus Hydroides, sometimes co-occurring on the same individual.

Supported by: National Science Foundation Grant #DEB76-18835.

ANATOMY OF AN OIL SPILL: LONG-TERM EFFECTS FROM THE GROUNDING OF THE BARGE FLORIDA OFF WEST FALMOUTH, MASSACHUSETTS

Howard L. Sanders, J. Frederick Grassle, George R. Hampson, Linda S. Morse, Susan Garner-Price and Carol C. Jones

To determine carefully the effects on the marine and estuarine benthos of #2 fuel oil spilled by the barge FLORIDA off West Falmouth, Massachusetts, we sampled for many months along an onshore-offshore gradient of pollution, and less intensively at unoiled sites. Analyses of hydrocarbons established that pollution was greatest and most persistent in the intertidal and subtidal zones of Wild Harbor River, less severe in degree and duration at stations farthest from shore. A variety of concurrent analyses showed that disturbance of the fauna was most severe and longest lasting at the most heavily oiled sites, and least severe but perceptible at lightly oiled stations. Patterns of disturbance were not related to granulometry of the sediments. Plants, crustaceans, fish, and birds suffered both high mortality immediately after the spill, and physiological and behavioral abnormalities directly related to high concentrations of the fuel oil. Five years after the spill its effects on the biota were still detectable, and partly degraded #2 fuel oil was still present in the sediments in Wild Harbor River and estuary.

In Press: Journal of Marine Research.

Supported by: Federal Water Pollution Control Administration Grant No. 15080FMW; The Environmental Protection Agency Grant No. R801001024; and the Woods Hole Oceanographic Institution.

DIVERSITY AS AN INDICATOR OF POLLUTION: CAUTIONARY RESULTS FROM MICROCOSM EXPERIMENTS

Woollcott Smith, Victoria R. Gibson, Susan Brown-Leger and J. Frederick Grassle

Data from two microcosm experiments (CEPEX and MERL) are examined to determine

whether diversity measures can provide an appropriate indicator of environmental stress. It is concluded that diversity is a rather stable community parameter, relatively insensitive to both natural variation and pollution over the short-term. When a community is not in stationary equilibrium with its environment it appears that changes in species composition and density are a more reliable indicator of stress than diversity measures.

Published in: Ecological Diversity in Theory & Practice, Inter Cooperative Pub. House, Fairland, MD, 1979, pp. 269-277. Edited by J.F. Grassle, G.P. Patil, W. Smith and C. Taillie.

Supported by: National Science Foundation Grant #OCE77-27446; Environmental Protection Agency Grant #R8039020; and NOAA Office of Sea Grant, Grant #04-8-M01-149.

#### B I O A C O U S T I C S

##### CLICK SOUNDS FROM ANIMALS AT SEA

William A. Watkins

Click sounds from captive cetaceans during echolocation experiments are usually very different from the clicks of the same species recorded at sea. The differences appear to be a result of the different echolocation tasks and behaviors of the animals at sea. This is in addition to the variability that results from the directional characteristics of clicks that change with the animals' orientation, and the differences in the bandwidths of recording equipment. The click sounds of different species encountered at sea are compared.

Supported by: Office of Naval Research Contract No. N00014-79-C-0071 NR 083-004.

##### CHARACTERISTIC FEATURES OF THE UNDERWATER SOUNDS OF CEPHALORHYNCHUS COMMERSIONII (MAMMALIA: CETACEA)

William A. Watkins and William E. Schevill

Underwater sounds recorded for Cephalorhynchus commersonii in the strait of Magellan and from captives at the Mystic Marinelife Aquarium (Mystic, CN) are analyzed and compared with the sounds of C. heavisidii from South Africa. Though the sounds of C. commersonii had less low frequency emphasis, the general sound structure of both species was similar and included clicks, short bursts of clicks and pulsed "cry" sounds. The "cry" sound appears to be characteristic of all the Cephalorhynchus species, including C. entropia (Cape Horn) and C. hectori (New Zealand). Underwater sound relationships, therefore, seem to offer another means of demonstrating the relationships in the Cetacea.

Supported by: Office of Naval Research Contract No. N00014-74-C0262 NR 083-004.

##### OBSERVATIONS AND RADIO TAGGING OF BALAENOPTERA EDENI NEAR PUERTO LA CRUZ, VENEZUELA

William A. Watkins, Giuseppe N. di Sciara and Karen E. Moore

Whales (Balaenoptera edeni) were observed and radio tagged near Puerto La Cruz, Venezuela (23 October to 13 November 1979). The whales appeared to be transient, remaining in the area not more than one day, so that even the two whales tagged with both highly visible streamers and radio beacons could not be located again. A change in the whales' behavior at dusk was indicated by the radio signals, with much shortened submergence times after dark. The modifications to the tag made prior to these experiments appear to have improved several aspects of the WHOI radio whale tag.

Supported by: Boeing Marine Systems, Ocean Industries Program, WHOI; Office of Naval Research Contract No. N00014-79-C-0071 NR 083-004.

ESTUARINE / RIVER  
ECOSYSTEMS

DETRITUS AND JUVENILE SALMON PRODUCTION  
IN THE NANAIMO ESTUARY: III. IMPORTANCE  
OF DETRITAL CARBON TO THE ESTUARINE  
ECOSYSTEM

Robert J. Naiman and John R. Sibert

Sources of autotrophic and allochthonous organic carbon available to the Nanaimo Estuary delta, British Columbia, were studied from 1974 to 1978. Annually, benthic microalgae produce  $4-55 \text{ gC}\cdot\text{m}^{-2}$ , phytoplankton  $\sim 7.5 \text{ gC}\cdot\text{m}^{-2}$ , and macroalgae  $0.9-7.5 \text{ gC}\cdot\text{m}^{-2}$ . *Zostera marina* ( $26.8 \text{ gC}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ ) and *Carex* ( $\sim 564 \text{ gC}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ ) are productive but enter the food web as detritus. Allochthonous sources are most important with organic matter from the river, especially dissolved organic carbon ( $\sim 2000 \text{ gC}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ ) and fine particulates ( $56 \text{ gC}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ ), contributing greatest amounts. The standing crop of organic detritus in the top 5 cm of sediments averages from 58 to  $233 \text{ gC}\cdot\text{m}^{-2}$ , depending upon the station. The timing of organic inputs are important, however. Seventy to 93% of total annual river inputs occur during autumn freshets, *Zostera* enters the food web during winter, *Carex* may contribute in early spring, and algae are productive over summer months. Activity and biomass of microbes are high most of the year in surface sediments but in the water column microbes are relatively active only during warmer months. Surface sediment ATP concentrations range seasonally from 3 to  $36 \mu\text{g/g sediment}^{-1}$ ; and concentrations in the water column range from  $<0.2$  to  $1.5 \mu\text{g/L}^{-1}$ . Microbial activity, measured with  $^{14}\text{C}$ -glucose, ranges seasonally from 4 to 20% uptake per hour for surface sediments and from  $<1$  to nearly  $40\%/h^{-1}$  in the water column. These results are compared with those from other studies and coupled to concurrent studies of meiofauna and salmon ecology to show a link between detritus, microbes, harpacticoid copepods, and the food, growth, and production of juvenile chum salmon (*Oncorhynchus keta*).

Published in: J. Fish. Res. Board Can.  
36: 504-520.

Supported by: National Research  
Council of Canada and Fisheries and  
Oceans Canada.

BENTHIC ORGANIC MATTER AS A FUNCTION OF  
STREAM ORDER IN OREGON

Robert J. Naiman and James R. Sedell

The quantity, size composition and presumed food quality of organic detritus is compared in four coniferous forest streams of different order in the Cascade Mountains of Oregon, U.S.A. The amount of detritus is greatest in small headwater streams, and decreases as stream order increases. Over 90% of detritus in all streams is woody debris; however, there is also a considerable quantity of fine particulate organic matter (FPOM:  $0.45 \mu\text{m}$  to  $1 \text{ mm}$ ) in small streams. Relative to the headwaters, downstream reaches have less coarse particulate organic matter (CPOM:  $>1 \text{ mm}$ ) and FPOM. The CPOM:FPOM ratio appears to increase from 1st to 3rd-5th order streams, and decreases thereafter.

The standing crop of benthic detritus and annual load of drifting particulate organic matter are used to evaluate the resistance and resilience of each stream order to perturbation. The results indicate that the pathway for attaining asymptotic ecosystem stability changes from one of resistance to resilience as stream order increases.

Presumed food quality of the benthic detritus, as judged by the carbon-to-nitrogen (C:N) ratio, chlorophyll *a* associated with detritus, and respiration rate, is poor for CPOM and shows no trend by stream order. Presumed food quality of FPOM is somewhat better since, in larger streams, more chlorophyll is associated with the detritus and the highest respiration rates are associated with smaller particles.

In Press: Arch. Hydrobiol.

Supported by: National Science  
Foundation Grant #BMS 75-07333.

RELATIONSHIPS BETWEEN METABOLIC PARAMETERS  
AND STREAM ORDER IN OREGON

Robert J. Naiman and James R. Sedell

The light regime, standing stock of chlorophyll, and five metabolic parameters were measured seasonally at four Oregon stream sites; Devils Club Creek (1st order), Mack Creek (3rd order), Lookout Creek (5th order), and the McKenzie River (7th order). Periphyton from pools and riffles, aquatic moss (*Fontinalis*), fine particulate organic matter (FPOM:  $0.5 \mu\text{m}$  -

1 cm), and coarse particulate organic matter (CPOM: > 1 cm) were examined separately for gross production (GP), net community production (NCP), diel respiration ( $R_{24}$ ), net daily metabolism (NDM), and the production to respiration (P:R) ratio. Total autotrophic production was found to increase in a downstream direction where more light is available; however, the efficiency of light utilization is greatest in heavily shaded Mack Creek. Detrital metabolism, per unit weight, is similar in all streams for each metabolic parameter. The standing stock of detritus though, is highest in headwater streams, decreasing as streams become larger. Therefore, the relative contribution of the detritus community to total metabolism decreases downstream. Mosses occur in significant quantities only in the McKenzie River and have an areal community respiration rate about twice that of periphyton; other metabolic parameters are nearly equal in this case. On an areal basis periphyton metabolism is much greater than detrital metabolism and, as a consequence, total stream metabolism and the P:R ratio increase downstream.

Gross production rates measured for these sites are some of the lowest recorded (0.1 to 1.0 g  $O_2$   $m^{-2} \cdot day^{-1}$ ). These rates are compared to those from other streams in the northwestern United States and western Canada, and the importance of photosynthesis to stream systems is demonstrated. The decomposition rate of the detrital standing stock is estimated to be 0.0029-0.0057  $m^{-2} \cdot day^{-1}$  and the turnover time is calculated to be 48-93 yrs for particles <10 cm diameter.

In Press: Can. J. Fish. Aquat. Sci.  
37: 000-000.

Supported by: National Science  
Foundation Grant #BMS 75-07333.

OXIDATION AND TRANSPORT OF ORGANIC CARBON  
IN THE AMAZON RIVER

Jeffrey E. Richey, James T. Brock,  
Robert J. Naiman, Robert C. Wissmar and  
Robert F. Stallard

Spatial and temporal patterns in the organic carbon load (< 1 mm) of the Amazon River indicated that oxidation was constant throughout the river at any one time, but was much greater at rising than at high water, whereas transport was constant. Total effective efflux, as the sum of oxidation and transport in the river, was about  $10^{14}$  g C/yr. Estimates for other river systems suggest that global riverine carbon fluxes exceed  $10^{15}$  g C/yr.

In Press: Science.

Supported by: National Science  
Foundation Grants DEB 76-82631 and  
BMS 75-07333.

THE ROLE OF DETRITUS AND THE NATURE OF  
ESTUARINE ECOSYSTEMS

John R. Sibert and Robert J. Naiman

The detritus concept in ecology has gone through changes attributable to theoretical and methodological advances. Prior to 1940, the importance of detritus in the nutrition of benthic communities was accepted by the scientific community. There was some understanding of the role of bacteria in nourishing invertebrates but this notion did not receive wide acceptance. In the 1940's and 1950's, attention was directed away from the study of detritus and bacteria toward photosynthesis and factors regulating primary productivity. In the 1960's, more attention was given to detritus and associated bacteria. The modern concept differs from the original only by increased appreciation of the role of bacteria in the detritus food chain.

Estuaries and detritus both appeared early in the history of the Earth prior to the origin of life. The first food chains, in the early Precambrian era, were detritus based. Photosynthesis developed later, possibly as a mechanism to augment the limited supplies of detritus. As the Earth's atmosphere became increasingly oxidized, the world ecosystem became increasingly dependent on photosynthesis to supply organic matter. Modern detritus based food chains are direct descendants of the primordial ecosystem. Estuaries receive large subsidies of imported organic matter and have well developed detritus food chains. The estuarine ecosystem should be considered to have two productive bases: detritus processing by microbes and photosynthesis.

In Press: Benthic Marine Dynamics,  
University of South Carolina Press,  
K. Tenore (ed.).

Supported by: National Research Council  
of Canada and Fisheries and Oceans  
Canada.

## F I S H E S

AN ELECTRONIC SIMULATION OF MOVING PREY

Adrianus J. Kalmijn and Matthew B. Weinger

In order to further the investigation of electroreception in elasmobranch fishes, an electronic device was developed which simulates the bioelectric fields of moving prey fish. Using primarily CMOS integrated circuitry, a digital control system switches a regulated dipole current along a linear array of electrodes, thereby producing a spatial sequence of prey-simulating fields. One has control over the position of the "fish" along the electrode array as well as the speed of travel (from 1 to 100 cm/sec) and the output current strength (from 1 to 10  $\mu$ A). The moving-prey simulator was designed to determine whether the elasmobranchs aim electrically and snap at their prey from a distance rather than zero in gradually, allowing for the movements of the target. Preliminary results indicate that the predators, after initiating their attacks, refrain from additional course corrections. Thus, the device offers the user the opportunity to study the dynamics of electrical prey detection.

Supported by: Eppley Foundation and Office of Naval Research Contract No. N00014-79-C-0071 NR 083-004.

THE SWIMBLADDER OF DEEP-SEA FISH. THE SWIMBLADDER WALL IS A LIPID-RICH BARRIER TO OXYGEN DIFFUSION

J. B. Wittenberg, D. E. Copeland, Richard L. Haedrich and J. F. Child

The inner wall (Tunica interna) of the swimbladder of deep sea gadiform and eel-like fishes is shown to be the barrier which resists outward diffusion of oxygen from the swimbladder. This wall consists of a thick, lipid-rich layer bounded externally and sometimes internally by silvery layers. We suggest that both silvery and lipid-rich layers act as barriers to gas diffusion. The swimbladder wall of freshly captured deep sea fishes is highly reflective and intensely white, suggesting that the lipids are in a highly ordered molecular array. The gross structure of the swimbladders of representatives of two groups of deep-living cod-like fishes, the rattail fishes and Antimora, and of two groups of deep-living eel-like fishes, the true eels and spiny eels, are described. Within the rattail fishes a closely related group of species (in Coryphaenoides) occurs

over almost the entire range of deep ocean depths. The length of the rete mirabile, the countercurrent organ of the swimbladder, increases with the depth at which each species occurs to a maximum of 65 mm in the deepest living species examined. A similar relation between the length of rete and depth is seen among the eels. The fraction of oxygen in the swimbladder gases of fishes captured at depths to 3000 m was 90-95 percent. At the greatest depths from which we have taken the same species the corresponding partial pressures of oxygen would be 460 to 520 atmospheres.

Supported by: National Science Foundation Grants OCE76-21878 and PCM74-05157.

## M I C R O B I O L O G Y

HETEROTROPHIC MICROBIAL ACTIVITY IN EXPERIMENTALLY PERTURBED MARINE ECOSYSTEMS

Paul A. Gillespie and Ralph F. Vaccaro

Intact ecosystems captured in coastal waters off Vancouver Island, British Columbia were subjected to experimental perturbation and monitored for subsequent changes in microheterotrophic activity. Sources of stress applied included sublethal but significant concentrations of plant nutrients, hydrocarbons and heavy metals. In stress situations the level of heterotrophic response appears to depend upon the overall impact of a particular perturbant on the entire community.

High concentrations of nitrate, phosphate and silicate enhanced photosynthesis but also accelerated the release of extracellular organic carbon which in turn enhanced microheterotrophic activity. Except for an initial, short-term retardation in organic carbon assimilation, hydrocarbon and heavy metal stress led to heterotrophic response patterns not unlike those associated with nutrient enrichment. In the latter instances there was also a release of organic substrates which could be readily utilized by a microbial population showing increased compatibility with the prevailing source of stress.

A long-term study of the course of events leading to marine microbial tolerance is also presented. Prolonged exposure of mixed bacterial species to sublethal heavy metal stress shows that the degree of tolerance attained is regulated by the duration and concentration of the perturbant

provided. If so, the extent of metal tolerance exhibited by a marine microbial population in nature may well reflect a dynamic condition regulated by past exposures of the local community to stress producing events.

In Press: Studies in Marine Environmental Pollution.

Supported by: National Science Foundation, IDOE Grant Numbers GX-39147 and OCE73-05941; A01, A02.

WIDESPREAD OCCURRENCE OF A UNICELLULAR, MARINE, PLANKTONIC, CYANOBACTERIUM

John B. Waterbury, Stanley W. Watson, Robert R. L. Guillard and Larry E. Brand

A description of a ubiquitous unicellular marine cyanobacterium, assignable to the genus *Synechococcus*, and its distribution and concentration in the oceans.

Published in: Nature, Vol. 277, pp. 293-294.

Supported by: National Science Foundation Grant DES75-21270.

MEASUREMENT OF BACTERIAL BIOMASS AS LIPOPOLYSACCHARIDE

Stanley W. Watson and John E. Hobbie

The biomass of bacteria in various waters can be estimated by measuring the amount of cellular bound lipopolysaccharide (LPS). LPS, which is present in the cell walls of gram-negative bacteria, including cyanobacteria, can be quantitated by using an extract of *Limulus* amoebocytes. In one special environment, an oceanic water column below the euphotic zone, the results of the LPS technique agreed very well with those of the direct count and adenosine triphosphate techniques for measuring bacterial biomass.

Published in: Native Aquatic Bacteria Enumeration, Activity, and Ecology, ASTM STP 695, J.W. Costerton and R.R. Colwell, Eds., American Society for Testing and Materials, 1979, pp. 82-88.

Supported by: National Science Foundation Grant #DES75-21270.

MICROBIOLOGICAL OBSERVATIONS AT THE SUBMARINE THERMAL SPRINGS OF THE GALAPAGOS RIFT AND THE EAST PACIFIC RISE SEA FLOOR SPREADING CENTERS

Holger W. Jannasch and Carl O. Wirsen

The recently discovered and unusually rich animal communities at two sea floor spreading centers in the central East Pacific Ocean, 2700 meters deep, appear to be run by chemosynthetic bacteria as primary producers of organic matter. The source of energy used by these microorganisms is geochemically reduced sulfur.

Published in: BioScience 29: 592-598.

Supported by: National Science Foundation Grant Numbers OCE77-19766 and OCE78-10457.

STUDIES ON THE MICROBIAL TURNOVER OF ORGANIC SUBSTRATES IN DEEP SEA SEDIMENTS

Holger W. Jannasch and Carl O. Wirsen

A technique is described of measuring the microbial *in situ* transformation of radiolabeled organic substrates into CO<sub>2</sub> and cell material in deep sea sediments using Na-<sup>14</sup>C-acetate as an example. The application of relatively inexpensive, free-falling and retrievable tripods makes this approach useful for the study of different microbial conversions in a wide variety of sediments at any ocean depth.

In Press: Actes des Colloques du C.N.R.S. (France).

Supported by: National Science Foundation Grant OCE77-19766 and ONR Contract N00014-74-C0262 NR 083-004.

MICROBIAL TURNOVER OF ORGANIC MATTER IN THE DEEP SEA

Holger W. Jannasch

The research submersible ALVIN and newly developed pressure-retaining water samplers were used in assessing the activity of natural microbial populations of the deep sea. The breakdown of chitin, agar, starch and gelatin as well as the turnover of radiolabeled defined organic compounds (amino acids and sugars) invariably was lower *in situ* or in the undecompressed samples than after retrieval and decompression. These facts have to be considered in estimating the natural remineralization process as well as the microbial decomposition of man-made pollu-

tants in the deep sea which comprises over 60 percent of the biosphere.

Published in: BioScience 29: 228-232.

Supported by: National Science Foundation Grant #OCE77-19766 and Office of Naval Research Contract #N00014-74-C0262 NR 083-004.

IN SITU INCUBATION EXPERIMENTS MEASURING THE METABOLISM OF DEEP-SEA AMPHIPODS AND THEIR MICROBIAL GUT FLORA

Holger W. Jannasch, Russell H. Cuhel, Carl O. Wirsen and Craig D. Taylor

A technique has been developed and field-tested for the trapping, feeding, and timed incubation of amphipods on the deep-sea floor. Data obtained from experiments using radiolabeled foodstuffs indicate that shifts within the labeled fractions of the major biological polymers make it possible to distinguish between the metabolism of the amphipods and that of their intestinal microflora.

Supported by: National Science Foundation Grant #OCE79-19178 and Office of Naval Research Contract #N00014-79-C-0071 NR 083-004.

DEEP SEA PRIMARY PRODUCTION AT THE GALAPAGOS HYDROTHERMAL VENTS

D. M. Karl, Carl O. Wirsen and Holger W. Jannasch

Dense animal populations surrounding recently discovered hydrothermal vents at the Galapagos Rift sea floor spreading center, 2550 m deep, are suggested to be sustained by microbial primary production. Energy in the form of geothermally reduced sulfur compounds emitted from the vents is liberated during oxidation and used for the reduction of CO<sub>2</sub> to organic matter by chemosynthetic bacteria.

In Press: Science.

Supported by: National Science Foundation Grant Numbers OCE77-19766 and OCE-7810457.

THE BACTERIAL BIOASSAY AND ASSESSMENTS OF INDUSTRIAL WASTE DISPOSAL AT OCEANIC DUMP SITE 106

Ralph F. Vaccaro and Mark R. Dennett

Changes in the bacterial uptake of <sup>14</sup>C labelled glucose in seawater are used to quantify some sublethal consequences of

Edgemoor and Grasselli waste disposal at Oceanic Dump Site 106.

The fractional amounts of waste in seawater which led to a 50 percent reduction in <sup>14</sup>C uptake ranged from 0.01-0.02 percent for Edgemoor waste and from 0.10-0.20 percent for Grasselli waste.

Both Edgemoor and Grasselli wastes give rise to an inhibitory bacterial response which exceeds that associated with their respective acid and caustic chemical compositions. Heavy metals appear to be the principle toxic components of Edgemoor waste while organic species appear to dominate with regard to Grasselli waste.

Evidence from ultra-violet radiation and from persulfate oxidation indicates a marked resistance to chemical attenuation and predict a capacity for above average environmental persistence for Grasselli waste.

Unlike Grasselli waste, Edgemoor waste undergoes vigorous reaction with seawater along with a precipitation of its heavy metal content. Such behavior is certain to influence its distribution kinetics and its impact on biological life processes of the ocean.

Mixtures of Edgemoor and Grasselli wastes impart an inhibitory response which is measurably less than that anticipated from the sum of their individual effects. This suggests the possibility of positive benefits from their coordinated release within the Dump Site area.

Uncertainty concerning net vs additive biological impacts from dual waste sources led us to initiate analyses of bioassay data derived from an appropriate hypothetical situation. An unambiguous solution developed from a graphical treatment of the experimental data is described.

In Press: Proceedings, First International Congress on Ocean Dumping, Sept. 1979.

Supported by: NOAA Grant #04-8-M01-42.

THE FAMILY NITROBACTERACEAE

Stanley W. Watson, Frederica W. Valois and John B. Waterbury

A discussion of the habitats, isolation, purification, preservation, and taxonomy of the family Nitrobacteraceae.

In Press: *The Prokaryotes*, Springer-Verlag.

Supported by: National Science Foundation Grant #DES75-21270.

## OCEANOGRAPHIC HISTORY

### GROWTH OF AN OCEANOGRAPHIC INSTITUTION

Richard L. Haedrich and Kenneth O. Emery

Oceanography as a profession is a very recent phenomenon, and most of its growth has occurred within the lifetimes of its present practitioners. We view its growth as a microcosm of the growth of science in general. Taking the Woods Hole Oceanographic Institution as an example, formal organization in 1930 was followed by a period of virtually no growth until World War II. Practical concerns of national interest produced a spurt in growth, but following the war there was a nearly equal reversal toward normalcy. With the establishment of the Office of Naval Research in 1946 and the National Science Foundation in 1950, the field grew exponentially. Part of the expansion included the development of large administrations, formal educational programs, oceanographic curricula, graduate students, and expensive inter-disciplinary and multi-investigator programs. At the same time, oceanographic investigations came to be conducted at many universities, colleges, and laboratories, rather than being monopolized by only a few large institutions. Funding leveled off in 1971, and then came the problems of coping with a steady state. As reflected in patterns of population structure, hiring and promotions, and leadership within departments, there were different responses to this change. While personalities may figure somewhat, the differences may be a function of differing stages of development of departments. For example, patterns in Biology, an old and established department, are different from those in Chemistry, a younger one.

## PHYSIOLOGY

### INDUCTION OF ARYL HYDROCARBON HYDROXYLASE ACTIVITY IN EMBRYOS OF AN ESTUARINE FISH

Robert L. Binder and John J. Stegeman

Exposure of *Fundulus heteroclitus* eggs over the course of development to polychlorinated biphenyls (PCBs) or whole No. 2 fuel oil induced aryl hydrocarbon hydroxylase (AHH) activity in eggs near hatching. Examination of similarly exposed yolk sac

larvae revealed that PCBs induced AHH activity in both the liver and extrahepatic tissues. AHH activity was seen both in hepatic and extrahepatic tissues of control larvae but was below detectable limits in control eggs. The levels in uninduced larval liver were about 50% of those in adult liver. Embryonic metabolism of environmental chemicals could be adaptive during yolk absorption but might also contribute to lesions by production of activated metabolites.

In Press: *Biochemical Pharmacology*.

Supported by: National Science Foundation Grant #OCE77-24517.

### GENETICS OF MORPHOLOGICAL VARIATION IN GEOGRAPHICALLY DISTANT POPULATIONS OF THE SEA URCHIN, *ARBACIA PUNCTULATA*

Nancy H. Marcus

Individuals of *Arbacia punctulata* from Woods Hole, MA and the northeastern Gulf of Mexico were reared from fertilized eggs through metamorphosis under comparable laboratory conditions. Interpopulation differences in spine length development were significant between pure bred offspring of these two widely separated geographic areas. Spine lengths of hybrid urchins were intermediate to pure bred animals. Interpopulation differentiation of specific portions of the genome is proposed to account for the observed phenotypic variation in spine length.

In Press: *Journal of Experimental Marine Biology and Ecology*.

Supported by: WHOI Postdoctoral Fellowship.

### CONCENTRATION OF ELEMENTS IN MARINE ORGANISMS CULTURED IN SEAWATER FLOWING THROUGH COAL FLY ASH

John H. Ryther, Thomas M. Losordo, A. Keith Furr, Thomas F. Parkinson, Walter H. Gutenman, Irene S. Pakkala and Donald J. Lisk

The uptake was measured of 14 elements by clams (*Mya arenaria*, *Mercenaria mercenaria*), oysters (*Crassostrea virginica*) and sand worms (*Nereis virens*) held in flowing seawater with a substrate of coal-fly ash over a four-month period.

Published in: *Bull. Environm. Contam. Toxicol.* 23: 207-210.

Supported by: National Science  
Foundation Grant Numbers ESR73-  
07838 and GI 38976.

A POSSIBLE ROLE FOR MICROSOMAL HEXOSE-6-  
PHOSPHATE DEHYDROGENASE IN MICROSOMAL  
ELECTRON TRANSPORT AND MIXED-FUNCTION  
OXYGENASE ACTIVITY

John J. Stegeman and Alan V. Klotz

Reduction of cytochrome c and cytochrome P-450 was readily linked to the oxidation of glucose-6-phosphate or galactose-6-phosphate by the enzyme hexose-6-phosphate dehydrogenase in vertebrate liver microsomes. In fish liver microsomes aminopyrine demethylation and benzo(a)pyrene hydroxylation dependent on hexose-6-phosphate dehydrogenase activity was as much as 60% of that seen with an artificial NADPH generating system. Hexose-6-phosphate dehydrogenase-dependent benzo(a)pyrene hydroxylase was seen in mouse liver microsomes also, although the percent of maximal activity was less. The results are consistent with the idea that hepatic hexose-6-phosphate dehydrogenase plays a role in providing reducing equivalents for microsomal electron transport and mixed-function oxygenase reactions.

Published in: Biochemical and Biophysical Research Communications, 87: 410-415.

Supported by: National Science  
Foundation Grant #OCE77-24517.

SEX DIFFERENCES IN CYTOCHROME P-450 AND  
MIXED-FUNCTION OXYGENASE ACTIVITY IN  
GONADALLY MATURE TROUT

John J. Stegeman and Mordechai Chevion

Levels of microsomal cytochrome P-450 and aminopyrine demethylase activity in liver and cytochrome P-450 in kidney of gonadally mature rainbow and brook trout were markedly greater in males than in females. Similar differences appeared in hepatic microsomal NADH but not in NADPH-cytochrome c reductase activity or cytochrome b<sub>5</sub>. When normalized to cytochrome P-450 content, benzo(a)pyrene hydroxylase activity in both liver and kidney was greater in females. In liver there was a pronounced sex difference in response of this activity to 7,8-benzoflavone, suggesting cytochromes P-450 of different catalytic function. Electron paramagnetic resonance spectra of hepatic microsomal

cytochromes P-450 in mature brook trout were not demonstrably different between males and females, and crystal field parameters indicate that axial ligands to the heme are the same in these as in other cytochromes P-450. Mixed-function oxygenase activities in liver of gonadally immature brook trout differed from those in mature fish, and there was no sex difference. The appearance of seasonally-dependent sex differences suggests fish may provide interesting models for studying regulation of sex-specific forms of cytochromes P-450.

In Press: Biochemical Pharmacology,  
Vol. 28.

Supported by: NOAA, Office of Sea Grant,  
Grant #04-6-158-44106.

TEMPERATURE INFLUENCE ON BASAL ACTIVITY  
AND INDUCTION OF MIXED FUNCTION OXYGENASE  
ACTIVITY IN FUNDULUS HETEROCLITUS

John J. Stegeman

Treatment of *Fundulus heteroclitus* acclimated to 6.5° with benzo(a)pyrene did not elicit any change in the levels of hepatic microsomal NADH- or NADPH-cytochrome c reductase activity, nor in the levels of cytochrome P-450 or its catalytic activities. However, the same treatment of fish at 16.5° resulted in a marked induction of benzo(a)pyrene hydroxylase and NADPH-cytochrome c reductase. Cytochrome P-450 content was also higher in the warm, treated fish and the Soret maximum of reduced, CO-treated microsomes was shifted to the blue. Levels of aminopyrine demethylase and NADH-cytochrome c reductase activities did not show a significant treatment effect. At neither temperature could treated and control fish be distinguished on the basis of in vitro inhibition of benzo(a)pyrene hydroxylase activity by 7,8-benzoflavone. Levels of NADPH-cytochrome c reductase and benzo(a)pyrene hydroxylase activities were greater in control *Fundulus* acclimated to 6.5° than to 16.5°, when normalized to microsomal protein, but not when based on body weight. The results indicate that habitat temperature alone may not affect the capacity for initial hydrocarbon metabolism in fish, but that it can strongly influence the induction of cytochrome P-450.

Published in: Journal of the  
Fisheries Research Board, Canada,  
Vol. 36, pp. 1400-1405.

Supported by: National Science  
Foundation Grant #OCE77-24517.

MIXED-FUNCTION OXYGENASE STUDIES IN  
MONITORING FOR EFFECTS OF ORGANIC  
POLLUTION

John J. Stegeman

Sex, season and temperature are among those factors known to influence the activity of hepatic cytochrome P-450-dependent mixed-function oxygenases in fish. These could mask induction of cytochrome P-450. Such factors notwithstanding, there has been success at demonstrating an association between environmental contamination by certain types of organic pollutants, notably petroleum, and elevated levels of fish mixed-function oxygenase activity (Burns, 1976; Payne, 1976; Stegeman and Sabo, 1976; Kuralec et al., 1977; Stegeman, 1978). Thus, mixed-function oxygenase activities in marine fish can be useful as environmental indicators in some circumstances. However, cytochrome P-450 systems in marine fish, and invertebrates, deserve continued research to determine their role in the fate and effects of organic pollutants and to define those conditions under which use in monitoring may be valid.

In Press: Rapport et Proces-Verbaux  
(The I.C.E.S. Series).

Supported by: National Science  
Foundation Grant Numbers OCE76-  
84415 and OCE77-24517.

IMPROVEMENT OF REVERSE-PHASE HIGH PRESSURE  
LIQUID CHROMATOGRAPHIC RESOLUTION OF  
BENZO(A)PYRENE METABOLITES USING ORGANIC  
AMINES: APPLICATION TO METABOLITES  
PRODUCED BY FISH

Kjell Tjessum and John J. Stegeman

Addition of primary organic amines, such as n-butylamine, to the mobile phase altered the capacity factors and selectivity of benzo(a)pyrene metabolites obtained with reverse-phase high pressure liquid chromatography on an ODS column. Separation of BP phenols in particular was improved with 8 of the 10 available metabolites resolved, including those known to be biologically produced. The method offers sufficiently improved resolution or convenience that it should prove useful in comparative studies of metabolism of benzo(a)pyrene and other polynuclear aromatic hydrocarbons. Applying the method to analysis of benzo(a)pyrene metabolites

produced in vitro by hepatic microsomes from the marine fish Stenotomus versicolor indicated the principal phenolic derivatives produced by this fish were 1-hydroxy, 3-hydroxy, 7-hydroxy and 9-hydroxybenzo(a)-pyrene.

Published in: Analytical Biochemistry  
99: 129-135.

Supported by: National Science  
Foundation Grant #OCE77-24516 and  
the Ocean Industries Program of the  
Woods Hole Oceanographic Institution.

P H Y T O P L A N K T O N

THE EFFECTS OF TEMPERATURE CONDITIONING  
ON THE DEVELOPMENT AND GERMINATION OF  
GONYAULAX TAMARENSIS HYPNOZYGOTES

Donald M. Anderson

Plankton samples from a dense bloom of the toxic red tide dinoflagellate Gonyaulax tamarensis Lebour were incubated in the laboratory to study the formation and development of thick-walled, overwintering cysts. The samples contained very few cysts, and fusing cells were seen only twice. However, thousands of elongate cysts were formed from the large posteriorly biflagellated cells (presumed to be planozygotes) that comprised over 50% of the initial motile population. The development of these new cysts (hypnozygotes) was then studied under different storage conditions. Each new hypnozygote lost its pigmentation and formed a thick cell wall during the first several days of storage, producing a starch-filled cell with a yellow accumulation body. At a rate determined by storage temperature (and not affected by light, dark, or nutrients), the starch reserves decreased, leaving areas of streaming microgranular cytoplasm at each pole of the cyst. The excretion of mucilaginous material was also observed. Periodic germination experiments showed that warm (22°C) temperatures accelerated the development process, with germination possible one month after formation, while cold storage (5°C) retarded development, with the first revivals after nearly four months. Excystment was initiated only after an applied stimulus - either a temperature increase or decrease depending on the previous storage conditions. Cysts formed during the late spring in temperate waters are thus capable of excystment several months later as fall temperatures decrease; those formed in the fall take

longer to mature, but are nevertheless fully viable after six months of overwintering. Alternating spring and fall blooms seeded by germinating populations of dormant cysts are thus possible, a finding consistent with recent field observations.

Supported by: NOAA, Office of Sea Grant, Grant Numbers 04-7-158-44079 and 04-8-M01-149; International Copper Research Association Project 252 and by the Ocean Industries Program of the Woods Hole Oceanographic Institution.

STUDIES OF ELEMENT INCORPORATION BY MARINE PHYTOPLANKTON WITH SPECIAL REFERENCE TO BARIUM

Donald C. Bankston, Nicholas S. Fisher, Robert R. L. Guillard and Vaughan T. Bowen

Small populations of various species of marine phytoplankton were batch-cultured in natural seawater media, under controlled conditions. Each culture was harvested by filtration during, or (in a few exceptional cases) after, the phase of exponential growth, dried, ashed, and then analyzed for barium, copper, and silicon by a technique employing dc plasma optical emission spectrometry.

Within the pooled sample of algal clones studied, and within each of three phylogenetic subsets of this sample, barium uptake was positively correlated with that of copper. The heaviest accumulators of barium and copper were the dinoflagellates. The diatoms and coccolithophores we studied were low accumulators of these elements. The uptake of barium and copper in several of the groups investigated was significantly lower in silicon-enriched, than in unenriched, media.

Certain algae having no known nutritive requirement for silicon, nevertheless accumulated it in sizeable amounts from silicon-enriched media. It is suggested that further research be done to determine whether this phenomenon ever occurs in the natural marine environment.

Published in: USDOE Environmental Quarterly Report, Proceedings of the New England Conference on Current Developments in Spectrochemical Excitation and Analysis.

Supported by: National Science Foundation Grant #OCE78-08858; and U. S. Department of Energy Contract #EY-76-S-02-3563.

COCCOLITH MORPHOLOGY AND PALEOCLIMATOLOGY ...II. CELL ULTRASTRUCTURE AND FORMATION OF COCCOLITHS IN CYCLOCOCCOLITHINA LEPTOPORA (MURRAY AND BLACKMAN) WILCOXON AND CEPHYROCAPSA OCEANICA KAMPTNER

Patricia L. Blackwelder, Larry E. Brand and Robert R. L. Guillard

Current interest in utilization of coccoliths for paleoclimate reconstruction necessitates background information on environmental limits for growth and coccolith production as well as examination of cell ultrastructure in specimens collected in the field and in cultured representatives. Successful isolation of the two geologically important species *Gephyrocapsa oceanica* (strain A674) and *Cyclococcolithina leptopora* (strain A650) allows investigation of ultrastructure in cultured forms. Fine structure of cells and coccoliths was observed in the SEM using critical point dried preparations and ultrastructure was examined with the transmission electron microscope.

Cell diameters in *G. oceanica* ranged from 2.5-4.0 microns and in *C. leptopora* from 7.5-9.5 as measured in thin section. In both species, a single layer of interlocking coccoliths surrounds each cell. Coccoliths are formed intracellularly and appear to form within Golgi-derived vesicles located near the nuclear membrane. Neither coccolithosomes nor scales were associated with the coccoliths. Arrangement and morphology of cell organelles was typical of the coccolithophorid group.

Formation and development of coccoliths in the two species resemble these processes in *Emiliana huxleyi* but differ from those of *Cricosphaera carterae*, notably in the absence of coccolithosomes and scales and in the fact that coccoliths are produced intracellularly one at a time.

Published in: Scanning Electron Microscopy 1979. III. Mineralized Tissue Workshop. Om Johari, Editor.

Supported by: National Science Foundation Grant Numbers OCF78-09643 and OCE77-10876; and National Science Foundation Predoctoral Fellowship.

A METHOD FOR THE RAPID AND PRECISE  
DETERMINATION OF ACCLIMATED PHYTOPLANKTON  
REPRODUCTION RATES

Larry E. Brand, Robert R. L. Guillard  
and Lynda S. Murphy

A rapid method for measuring, simultaneously, the asexual reproduction rates of hundreds of phytoplankton cultures is described. This method is based on the daily measurement of in vivo chlorophyll fluorescence read directly in the culture tubes. Hundreds of these culture tubes, containing specially prepared culture medium, can be maintained in identical environments in specially designed constant environment devices. The method is capable of measuring the acclimated reproduction rates of phytoplankton cultures with an error of 3-4% (coefficient of variation). Complete acclimation, crucial to the detection of small genetic differences between clones, takes one to three weeks, thus necessitating long-term experiments. Studies using the methods described indicate that, in a constant environment, coccolithophores and dinoflagellates reproduce at constant rates, but diatoms do not.

Supported by: National Science  
Foundation Grant Numbers OCE77-  
10876, OCE78-08858 and OCE79-03621.

OXYGEN ISOTOPE ANALYSES OF COCCOLITHS  
GROWN IN CULTURE: SPECIES DOMINANT IN  
PLEISTOCENE-HOLOCENE NANNOFOSSIL  
ASSEMBLAGES

W. C. Dudley, J. C. Duplessy,  
P. L. Blackwelder, Larry E. Brand  
and Robert R. L. Guillard

Oxygen isotope analyses have been performed on coccoliths from monospecific cultures of Gephyrocapsa oceanica, Emiliania huxleyi, and Cyclococcolithina leptopora, and on tests of Thoracosphaera heimi. The three coccolithophorid species are among the most important for coccolith stable isotope paleoclimatic studies, as they dominate many nannofossil assemblages throughout much of the Pleistocene and Holocene. Over 70 different culture samples were analyzed, representing growth temperatures from 12° to 28° Celsius. The results indicate a "vital effect" in the fractionation of oxygen isotopes in the coccoliths of all the species studied. The  $^{18}\text{O}$  VS temperature relationship of the coccoliths falls into two definite groups. The  $^{18}\text{O}$  of coccoliths of G. oceanica and E. huxleyi exhibits a strong temperature

dependence ( $y = 3.68 - 0.17t$ ) but are approximately 1‰ positive relative to equilibrium precipitation of calcium carbonate. The  $^{18}\text{O}$  of coccoliths of C. leptopora and of tests of T. heimi are quite similar to those reported for coccoliths of C. carterae, showing a strong temperature dependence ( $y = 0.09 - 0.16t$ ) but approximately 2.5‰ negative relative to equilibrium. An understanding of the "vital effect" in isotopic fractionation exhibited by coccolith species groups is essential for the interpretation of oxygen isotope paleoclimatic curves derived from assemblages of calcareous nannofossils.

Supported by: National Science  
Foundation Grant Numbers OCE78-  
08858 and OCE79-03621.

EFFECT OF NITROGEN SOURCE AND GROWTH RATE  
ON PHYTOPLANKTON-MEDIATED CHANGES IN  
ALKALINITY

Joel C. Goldman and Peter G. Brewer

Continuous cultures of the marine chrysophyte Dunaliella tertiolecta were grown on four different nitrogen sources:  $\text{NO}_3^-$ ,  $\text{NO}_2^-$ ,  $\text{NH}_4^+$  and urea. Alkalinity changes were consistent with a simple stoichiometric model in which  $\text{OH}^-$  production is balanced by  $\text{NO}_3^-$  and  $\text{NO}_2^-$  uptake,  $\text{H}^+$  production is balanced by  $\text{NH}_4^+$  uptake and no change occurs when the uncharged species urea is assimilated. Neither the influent N concentration nor the growth rate had any effect on the 1:1 stoichiometry between N-uptake and alkalinity change. These results preclude the possibility of excretion of an organic acid (e.g., glycolic acid) stronger than carbonic acid. However, excretion of a weak organic acid or a salt of a strong organic acid cannot be ruled out. In general, our results are consistent with the notion that excretion of glycolic acid by healthy marine phytoplankton cells is minimal.

In Press: Limnology and Oceanography.

Supported by: NOAA, Office of Sea Grant,  
Grant #04-8-M01-149.

STEADY STATE GROWTH AND CHEMICAL  
COMPOSITION OF THE MARINE CHLOROPHYTE  
DUNALIELLA TERTIOLECTA IN NITROGEN-LIMITED  
CONTINUOUS CULTURES

Joel C. Goldman and Dwight G. Peavey

The marine chlorophyte Dunaliella tertiolecta was grown in continuous cultures under  $\text{NH}_4^+-\text{N}$ ,  $\text{NO}_2^--\text{N}$ ,  $\text{NO}_3^--\text{N}$ , and urea-N

limitation. The effect of the nitrogen cell quota ( $Q_n$ ) on the steady-state growth rate ( $\mu$ ) was the same regardless of the N source. The relationship between  $\mu$  and  $Q_n$  was well described by the Droop equation, but only up to the true maximum growth rate  $\hat{\mu}$  (= cell washout rate). The ratio between the minimum cell quota ( $k_Q$ ) and the maximum cell quota ( $Q_m$ ) was 0.19. Hence, there is no substitute for determining  $\mu$  experimentally. That there was no difference in growth response to different N sources suggests that no internal pooling of inorganic nitrogen occurred. Both the carbon ( $Q_c$ ) and phosphorus ( $Q_p$ ) cell quotas under N limitation increased with increasing  $\mu$  in a threshold fashion: virtually no change in either cell quota up to  $\approx 0.8 \hat{\mu}$ , followed by a rapid and large increase up to  $\hat{\mu}$ . In addition, in the region of low  $\mu$ , there was an increase in  $Q_p$  with a decreasing medium N/P ratio of between 15 and 5 (by atoms). The results generally indicate the physiological limits in cellular constituency under N limitation. The usefulness of this information, however, in describing the response of natural populations of marine phytoplankton to transient nutrient exposures on the temporal and spatial microscales that most likely exist is of limited value.

Published in: Applied and Environmental Microbiology, Vol. 38, pp. 894-901.

Supported by: NOAA, Office of Sea Grant, Grant #04-8-M01-149, and National Science Foundation Grant #OCE78-19420.

#### BIOENGINEERING ASPECTS OF INORGANIC CARBON SUPPLY TO MASS ALGAL CULTURES

Joel C. Goldman

The study involves a thorough investigation of the inorganic carbon requirements of algae (both micro and macro species) in mass culture conditions. Major research topics considered include: 1) the growth kinetics of various freshwater and marine algae under inorganic limitation at different pH levels; 2) comparisons of growth with bubbled  $CO_2$  and  $HCO_3^-$  alkalinity as inorganic carbon sources at varying pH levels; 3) effects of pH on algal growth under non-carbon limiting conditions; 4) effects of mixing in inorganic carbon limiting and non-limiting situations on algal growth; 5) growth kinetics under carbon saturation but light limitation. Based on results to date, it appears that certain marine microalgae appear to be far more

tolerant of high pH ( $> 9$ ) than other species.  $HCO_3^-$ , if supplied in excess and with proper pH control, can meet the inorganic carbon requirements of marine algae. Efficiency of use is 90% at  $HCO_3^-$  concentrations four times greater than in natural seawater. Based on the growth kinetics of fresh water green algae under  $HCO_3^-$  limitation, virtually 100% assimilation is possible at all growth rates up to just before cell washout. Hence, maximum yields under carbon limitation occur at very high growth rates. In addition, it has been shown that the supply and mass transfer rates of gaseous carbon dioxide rather than the concentration of carbon dioxide in the gas mixture is the critical factor in ensuring an adequate supply of inorganic carbon.

Published in: Proceed. 3rd Annual Biomass Energy Systems Conf. pp. 25-32 Report No. SERI/TP-33-285.

Supported by: U.S. Dept. of Energy Contract No. ET-78-S01-4812.

#### TEMPERATURE-INFLUENCED VARIATIONS IN SPECIATION AND CHEMICAL COMPOSITION OF MARINE PHYTOPLANKTON IN OUTDOOR MASS CULTURES

Joel C. Goldman and Roger Mann

Between September, 1976 and July, 1977 Phaeodactylum tricoratum was replaced as the dominant species by Skeletonema costatum as temperatures fell below  $10^\circ C$  in the fall in an outdoor pond supplied with a mixture of wastewater and seawater. P. tricoratum returned in the spring as the major species when temperatures rose above  $10^\circ C$ . However, in an adjacent pond in which only nitrogen and phosphorus were added in excess, P. tricoratum dominated throughout the entire study period even though the temperature varied between  $0^\circ$  and  $25^\circ C$ . We suspected that the difference in species dominance in the two ponds occurred because S. costatum requires silicon, which was present in sufficient quantities only in the wastewater enriched pond, whereas P. tricoratum does not have a specific requirement for this nutrient. The cellular chemical composition of P. tricoratum varied in a U-shaped fashion with changing temperature: minimum values for the cellular carbon, nitrogen, and chlorophyll contents were displayed at  $15^\circ-20^\circ C$  and maximum values at  $3^\circ C$  and  $25^\circ C$ . Both the cellular carbon:nitrogen and carbon:chlorophyll ratios by weight were invariant with changing temperatures at  $\approx 6:1$  and  $50:1$  respectively, indicating nutrient saturation. Only under conditions

of nutrient saturation, which can be established in various ways, can the influence of temperature on phytoplankton physiology be separated from nutrient-related factors.

In Press: Journal Experimental Marine Biology and Ecology.

Supported by: National Science Foundation Grant #OCE79-19420 and NOAA Office of Sea Grant #04-6-158-44106.

PHAEODACTYLUM TRICORNUTUM BOHLIN  
(BACILLARIOPHYCEAE) IS NOT A LIGHT PIPE

Robert R. L. Guillard and Nina S. Allen

By means of fluorescence microscopy we showed that light incident on the clear membranous "arms" of the fusiform *Phaeodactylum* cell is not transferred to the chloroplast. Thus, the known photosynthetic efficiency of *Phaeodactylum* at low light intensity is not due to enhanced light capture by the arms.

Supported by: National Science Foundation Grant #OCE78-08858.

AN ASYMMETRIC FORMULATION OF THE  
DISTRIBUTION CHARACTERISTICS OF  
PHYTOPLANKTON SPECIES: AN INVESTIGATION  
IN INTERPRETATION

Edward M. Hulburt

A number of phytoplankton species decrease appreciably in abundance in the shallow marginal areas of the western North Atlantic Ocean. These are oceanic species. They differ from other species that increase very much in abundance in these marginal areas, indicating the greater availability of nutrient there. A scheme is presented such that both nutrient and the capacity to absorb it are productive of any given species. A species so produced can be maintained against the normal, oceanic, steady-state losses of predation and sinking. Or a species so produced can increase in abundance toward shore due to greater nutrient there and the capacity to absorb it. In order to have some species be less abundant toward shore the scheme has a contradictory part wherein the species is both present and not present. This contradictory part is expanded to having the species present, having something preventive of the species, and having the species then not present. This portrays the oceanic species' shoreward decrease, because, of course, it must be first there to be secondarily prevented from being there.

Published in: Marine Science Communications Vol. 5, pp. 245-268.

Supported by: Woods Hole Oceanographic Institution.

USE OF QUINE'S VIEW OF "OBJECT" IN  
ASSESSING PRODUCTIVITY OF MARINE  
PHYTOPLANKTON

Edward M. Hulburt

The identifiable phytoplankton species between New Zealand and Hawaii can be divided into the fraction that grows readily under improved conditions, composed of diatom species plus *Coccolithus huxleyi* and *Gephyrocapsa oceanica*, and the complementary fraction of other species that do not so grow. Samples containing a higher proportion of the first fraction have a higher growth capacity. The collection of samples between New Zealand and Hawaii having varying proportions of the two fractions has a varying growth capacity. This collection is the single entity that is directly controlled both by its own variable growth capacity and by the variable oceanic nutrient concentration between New Zealand and Hawaii.

Supported by: Woods Hole Oceanographic Institution.

EVOLUTION OF RESISTANT PHYTOPLANKTON  
STRAINS THROUGH EXPOSURE TO MARINE  
POLLUTANTS

Lynda S. Murphy and Robert R. L. Guillard

When pollutants are introduced into a phytoplankton community, there results a change in community structure that may or may not be accompanied by a change in biomass. The most obvious change is a decrease in diatoms and often dinoflagellates, and an increase in microalgae. Three mechanisms could permit such a change: first, changes in predators, secondly, emergence to dominance of species all of whose members are better adapted to the changed environment, and thirdly, takeover by species having greater variability of individuals and thus, greater potential for genetic adaptation. We report here on genetic variability that could account for such adaptability.

We evaluated the responses of 17 clones of marine diatoms isolated from a range of environments to an industrial waste now disposed of at the oceanic dumpsite DWD

106. The clones showed a wide range of sensitivity to the stress and there were no correlations with latitude, distance from shore, temperature regime, salinity, nor general environmental stability. The three neritic clones from heavily polluted waters were much less sensitive than were the other neritic and the oceanic clones. Further, we surveyed cupric ion sensitivity in 15 clones of phytoplankton isolated from different neritic environments. All extremely resistant clones came from regions known or presumed to be heavily polluted. These data suggest that phytoplankton can develop strains resistant to many classes of marine pollutants.

In Press: MESA Symp. on the Ecological Effects of Env. Stress, NOAA.

Supported by: NOAA Office of Sea Grant #04-8-M01-41 and National Science Foundation Grant #OCE78-08858.

THE EFFECT OF ENVIRONMENTAL ORIGIN ON THE RESPONSE OF MARINE DIATOMS TO CHEMICAL STRESS

Lynda S. Murphy and Rebecca A. Belastock

We have compared the responses of 17 clones in the marine diatoms Thalassiosira pseudonana and Skeletonema costatum to an industrial waste now disposed of at the oceanic dumpsite DWD 106. Eight clones are of oceanic origin and eight are neritic. Of the neritic clones, three are from heavily polluted estuaries and five are from relatively unpolluted waters. The clones showed a wide range of sensitivity to the chemical stress. There were no correlations with latitude or distance from shore in the oceanic clones nor with temperature regime or salinity in the neritic ones. The three clones from heavily polluted waters were much less sensitive than were the other neritic clones which came from relatively clean water. These were slightly less sensitive than were the oceanic clones, but there was considerable overlap in the responses of these two groups. For these 17 clones, a recent history of environmental pollution had at least as much influence on clonal sensitivity to chemical stresses as did the long-term stability, or lack of it, of the environment from which isolation was made.

Published in: *Limnol. & Oceanog.* 25(1): pp. 160-165.

Supported by: NOAA Grant #04-M01-41 and National Science Foundation Grant #OCE78-08858.

IMPACT OF NUTRIENT ENRICHMENT ON WATER USES

John H. Ryther and C. B. Officer

The uses of estuaries and their value to man are very much affected by the amount of nutrients that enter and accumulated within them and the resulting growth of algae and other aquatic plants. The relationship is not, however, linear because some algal growth is beneficial and essential for almost any use, while excessive growth causes both esthetic and ecological problems. The relationship is further complicated by the fact that different uses of the estuary (esthetic, recreational, commercial, nutritional) require different levels of plant production.

More important than the quantitative aspects of nutrient input and algal growth, however, are their qualitative characteristics. Certain species of phytoplankton, such as centric diatoms, grow and decompose rapidly, are excellent food organisms for higher trophic levels, do not accumulate in the water or on the bottom, and seldom create problems. Others, such as non-motile green and bluegreen algae, grow more slowly but do not readily decompose, are not eaten or assimilated by animals, accumulate in the water and on the bottom, and frequently produce noxious water blooms and anoxic benthic and deep-water conditions resulting in fish kills and other serious ecological problems. Still other algae (flagellates of various kinds) are intermediate in their effects upon estuarine uses and values.

In Press: Proc. Inter. Symp. Nutrient Enrichment in Estuaries.

Supported by: Department of Energy Contract No. EY-S-02-2532.

EFFECTS OF COPPER, CHLORINE, AND THERMAL ADDITION ON THE SPECIES COMPOSITION OF MARINE PHYTOPLANKTON

James G. Sanders, John H. Ryther and John H. Batchelder

The introduction of low levels of copper, chlorine, and thermal elevation caused significant changes in the biomass and species composition of natural phytoplankton cultured under ambient nutrient concentrations and natural light. Chlorine stress caused a rapid decline in biomass relative to control assemblages. Copper addition caused a gradual decline in biomass over the period studied. Both chlorine and cop-

per additions led to a reduction in species diversity. Thermal addition of 2°C caused a slight increase in biomass, but did not affect species diversity. Higher levels of thermal addition during the summer led to greatly decreased levels of biomass. In general, addition of stress led to a reduction in centric diatoms, especially Chaetoceros spp., and predominance of microflagellates. These changes were more pronounced in copper and heat-stressed tanks than in the chlorine-stressed tanks, perhaps due to rapid degradation of the added chlorine.

Supported by: Department of Energy  
Contract #EY-76-S-02-2532.

OPPORTUNISTIC DOMINANCE OF A STRESSED  
MARINE PHYTOPLANKTON ASSEMBLAGE BY  
THE PENNATE DIATOM AMPHIPRORA

James G. Sanders, John H. Batchelder  
and John H. Ryther

The accidental addition of 25-40 µg/l of copper to natural phytoplankton assemblages in experimental ecosystems during summer months led to blooms of Amphiprora sp. which flourished virtually as monocultures even after copper levels decreased. This diatom genus is not common in Vineyard Sound or these experimental systems, and is probably able to successfully compete with the usual dominant species only when those species are stressed. Amphiprora is obviously resistant to copper, since it was able to attain densities much greater than those found in control assemblages.

Supported by: Department of Energy  
Contract #EY-76-S-02-2532.

EFFECTS OF ARSENIC SPECIATION AND  
PHOSPHATE CONCENTRATION ON ARSENIC  
INHIBITION OF SKELETONEMA COSTATUM  
(BACILLARIOPHYCEAE)

James G. Sanders

Arsenate is taken up readily by Skeletonema costatum (Greville) Cleve due to its chemical similarity to phosphate, and it inhibits primary productivity at concentrations as low as 67 nM when the phosphate concentration is low. A phosphate enrichment of greater than 0.3 µM alleviates this inhibition; however, the arsenate stress causes an increase in the cell's requirement for phosphorus. Arsenite is also toxic to Skeletonema at similar concentrations. Methylated species, such as dimethylarsinic acid, did not affect cell productivity at the levels examined. Thus, the reduction and methylation of arsenate

to dimethylarsinic acid by the cell produces a stable, non-toxic compound.

Published in: Journal of Phycology  
15: pp. 424-428.

Supported by: Department of Energy #EY-76-S-09-0890, and National Science Foundation IDOE Grant #OCE75-06423.

THE UPTAKE AND REDUCTION OF ARSENIC  
SPECIES BY MARINE ALGAE

James G. Sanders and Herbert L. Windom

Phytoplankton take up As(V) readily, and incorporate a small percentage of it into the cell. The majority of the As(V) is reduced, methylated, and released to the surrounding media. This uptake and subsequent release in a reduced or methylated form causes large changes in the speciation of arsenic in the culture media; up to 50% of the As(V) may be reduced. The speciation of arsenic in phytoplankton and Valonia also changes when As(V) is added to cultures. The addition generally causes an increase in the proportion of organic arsenic. Arsenate and phosphate compete for uptake by algal cells. The uptake and subsequent reduction and methylation of As(V) is a significant factor in determining the arsenic biogeochemistry of productive systems. Calculations based on the measured rates of reduction indicate that 15-20% of the total arsenic is reduced by phytoplankton during the spring and fall blooms on the continental shelf.

Published in: Estuarine and Coastal  
Marine Science, 10.

Supported by: Department of Energy  
#EY-76-S-09-0890; National Science  
Foundation IDOE Grant Numbers OCE75-06423, OCE76-22717 and OCE73-09763.

ARSENIC CYCLING IN MARINE SYSTEMS

James G. Sanders

The arsenic cycle in productive, near-shore marine systems is complex, involving both geochemical inputs and outflows, and biological mediation. The major input to the Georgia Bight is intrusion of subsurface Gulf Stream Water; in other marine systems, river run-off and atmospheric deposition may provide a large percentage of the arsenic input. Indiscriminate biological uptake is responsible for changes in arsenic speciation, involving approximately 20% of the dissolved arsenate pool and resulting in measurable concentrations of reduced and methylated arsenic species.

The overall cycle is similar to the phosphate cycle, however regeneration time for arsenic is much slower.

In Press: Mar. Environ. Res.

THE IMPACT OF CHLORINE ON THE SPECIES COMPOSITION OF MARINE PHYTOPLANKTON

James G. Sanders and John H. Ryther

Low levels of chlorine can significantly affect the species composition of natural assemblages of marine phytoplankton. Seventy-two hour bioassays performed under nutrient enrichment and artificial light had large shifts in the species composition of the phytoplankton with respect to unstressed controls. With the exception of the more resistant Skeletonema costatum, centric diatoms were generally more sensitive than pennate diatoms and flagellates. Chaetoceros sp. and Thalassiosira sp. were especially sensitive to chlorine addition, while S. costatum, Pinnularia sp., Tropidoneis sp., unidentified pennate diatoms, and microflagellates were not affected at concentrations of added chlorine up to 0.5 mg·l<sup>-1</sup>. Assemblages grown in large outdoor tanks under ambient nutrient concentrations showed similar changes in species composition; however, the magnitude of the changes was not as large. S. costatum was more important in the chlorine-stressed assemblages, as were microflagellates. Chaetoceros spp. showed a mixed response, which may indicate that individual species of Chaetoceros have differing sensitivities to chlorine.

In Press: Water Chlorination:  
Environmental Impact and Health  
Effects, Vol. 3, pp. 631-639.

Supported by: Department of Energy  
#EY-76-S-02-2532.

S A L T M A R S H E S

TRACE ELEMENT ENRICHMENTS DURING THE DECOMPOSITION OF SPARTINA ALTERNIFLORA

Ronald J. Breteler, Anne E. Giblin,  
John M. Teal and Ivan Valiela

Concentrations of mercury, copper, zinc, chromium, iron, and manganese were measured at intervals of 5, 10, and 24 weeks in decaying Spartina alterniflora. Litter samples were obtained from: 1) low marsh habitats, flooded a major portion of each tidal cycle, 2) high marsh habitats, flooded for shorter periods during most

high tides. The study area included experimental salt marsh plots, treated with a metal-containing sewage sludge, and untreated marsh. Overall, highly significant increases were found in the concentrations of Hg, Cu, Fe, and Zn. Significant increases were further observed in Cr and Mn in tall form, untreated litter. The metal concentration increases were related to the strength with which metals were bound by the decaying plant material. Metal concentrations of decomposed plants were therefore higher in dwarf S. alterniflora than in the more frequently inundated tall form. Decay weight losses may partially account for metal enrichments, depending on the bonding strength and location of the element. Differences in the nitrogen content of certain litter types could not explain the magnitude of the metal increases observed. In general, no metals were absorbed from the sludge-treated marsh soil.

Supported by: Grants from the Victoria Foundation and the Woods Hole Oceanographic Institution.

RETENTION AND FATE OF EXPERIMENTALLY ADDED MERCURY IN A MASSACHUSETTS SALT MARSH TREATED WITH SEWAGE SLUDGE

Ronald J. Breteler, John M. Teal  
and Ivan Valiela

A simple, rapid, precise, and reproducible procedure is described for sample preparation, extraction, and measurement of total mercury in peaty sediments, plants, and animal tissues. Various amounts of a heavy metal containing dried sewage sludge were applied to experimental plots in a New England salt marsh. This treatment resulted in elevation of mercury levels in the surface 5 cm of the soil. Discrepancies in the bulk density of marsh sediments corresponded with interparticle spaces and detritus/mineral ratios in the peat matrix. Mass balance calculations showed that wetlands covered with tall Spartina alterniflora lost mercury considerably faster than higher marsh locations which retained virtually all mercury added. The shortest half-life of mercury calculated was four years. Grain size analyses of peat and sewage sludge suggested that mercury in the higher intertidal range remained associated with sludge components. Biochemical and physical processes affecting the dissipation of mercury from creek-side sediments are discussed.

Supported by: Victoria Foundation and the Woods Hole Oceanographic Institution.

THE AVAILABILITY OF MERCURY TO  
SALT MARSH ORGANISMS

Ronald J. Breteler, Ivan Valiela  
and John M. Teal

Mercury concentrations were measured in sediments, marsh grasses, mussels, and fiddler crabs in salt marsh plots treated with a mercury-containing commercial sludge fertilizer and in clean and industrially contaminated marshes. Mercury accumulated in the roots of the marsh grass Spartina alterniflora, rather than in rhizomes or above-ground tissues. Mercury concentrations did not increase in marsh organisms within the plots treated with sewage sludge. Highest concentrations of mercury were found in animals living in the least organic marsh sediments. Mercury was closely associated with small (< 0.5 mm) detrital particles. Only between 10 and 30% of the total soil mercury was complexed by the humic and fulvic acid fraction of the marsh soil.

Supported by: Victoria Foundation;  
NOAA Office of Sea Grant, Grant  
#04-7-158-44104; and the Woods Hole  
Oceanographic Institution.

THE WEST FALMOUTH OIL SPILL: HYDROCARBONS  
IN THE SALT MARSH ECOSYSTEM

Katherine A. Burns and John M. Teal

Marsh surface sediments, cores, and organisms were analysed for hydrocarbons from one to seven years after the spill in September 1969 of No. 2 fuel oil at West Falmouth, Massachusetts. All organisms analysed showed contamination initially. Fundulus were nearly free of oil after one year but Uca remained heavily contaminated for at least four years. Alkanes disappeared in sediments after about four years while heavy aromatics and raphthenes persisted throughout the study.

Published in: Estuarine Coastal Marine  
Research, Vol. 8: pp. 349-360.

Supported by: Victoria Foundation;  
Bureau of Commercial Fisheries,  
Fish and Wildlife Grant N1.14-17-  
007-1128(G); and National Science  
Foundation Grant #GA-40987.

THE GROWTH OF FUNDULUS HETEROCLITUS IN  
FERTILIZED AND UNFERTILIZED PLOTS ON  
A CAPE COD SALT MARSH

Michael S. Connor, John M. Teal  
and Ivan Valiela

The growth rate of the killifish Fundulus heteroclitus feeding in a fertilized and a control plot in Great Sippewissett Marsh, Massachusetts, was measured by following the average size of individuals under the first peak in a size histogram and by following marked individuals directly. Growth rate estimates obtained by the marked individual method were about 25% greater than those from the size histogram method. Fish in the fertilized plot grew significantly faster than those in a control plot during the three different intervals growth was compared. Fish growth rate peaked in July, though potential food items remained at high levels throughout the summer.

Supported by: Victoria Foundation;  
NOAA Office of Sea Grant, Grant  
Numbers 04-8-M01-149 and  
04-7-158-44104.

SULFATE REDUCTION IN A NEW ENGLAND  
SALT MARSH

Robert W. Howarth and John M. Teal

Sulfate reduction rates were measured for two years in the peat of a salt marsh by a radiotracer technique. Rates are high throughout the peat, from the surface to more than 20 cm deep. The integrated annual rate is about  $75 \text{ mol SO}_4^{2-} \cdot \text{m}^{-2} \cdot \text{yr}^{-1}$ , the highest yet reported for any natural ecosystem. Sulfate reduction accounts for the consumption of  $1,800 \text{ g org} \cdot \text{C} \cdot \text{m}^{-2} \cdot \text{yr}^{-1}$ , about equal to net primary production in the marsh. Respiration using other electron acceptors (such as oxygen or nitrate) is much less important. Sulfate reduction rates in the peat of the salt marsh are probably high for at least three reasons: the belowground production of Spartina alterniflora provides a large, annual input of organic substrates over a depth of some 20 cm; sulfate is rapidly resupplied to the peat in infiltrating tidal waters, so that sulfate depletion never limits the rate of reduction; and sulfide concentrations remain below toxic levels. The stable pyrite ( $\text{FeS}_2$ ) is a major end product of sulfate reduction in the marsh peat while iron monosulfide ( $\text{FeS}$ ) is not. If the incorporation of  $^{35}\text{S}$  into pyrite were not measured, the  $(^{35}\text{S})\text{SO}_4^{2-}$  reduction measurements would greatly underestimate the true rate of sul-

fate reduction. Pyrite acts largely as a temporary store of reduced sulfur, with seasonal changes in its concentration.

Published in: *Limnology and Oceanography*, Vol. 24(6), pp. 999-1013.

Supported by: National Science Foundation Grant #DEB78-03557 and the Woods Hole Oceanographic Institution.

INHIBITION OF DETRITUS FEEDING BY CINNAMIC ACIDS

Ivan Valiela, Lauren Koumjian, Tony Swain, John M. Teal and John E. Hobbie

Cinnamic acids produced by the salt marsh cordgrass, *Spartina alterniflora*, persist after the death of the plant, and can be found in the resulting detritus. These compounds, especially ferulic acid, inhibit feeding by detritivores at concentrations found in nature and may be a major factor controlling the rate of decay of organic matter.

Published in: *Nature* 280: pp. 55-57.

Supported by: National Science Foundation Grants #DEB76-83877 and SPI 76-83465 A01.

THE NITROGEN BUDGET OF A SALT MARSH ECOSYSTEM

Ivan Valiela and John M. Teal

Salt marshes reduce oxidized nitrogenous compounds introduced into the marsh by fresh water and export ammonium and particulate nitrogen to coastal waters and nitrogen gas to the atmosphere.

Published in: *Nature* 280: pp. 652-656.

Supported by: National Science Foundation Grant Numbers GA-43008 and GA-43009.

THE STRUCTURE OF COMMUNITIES OF HERBIVOROUS INSECTS IN SALT MARSHES: THE EFFECT OF EXPERIMENTAL NUTRIENT ADDITIONS, PREDATION AND POPULATION DYNAMICS

Susan W. Vince, Ivan Valiela and John M. Teal

Factors regulating the numbers and species of herbivorous insects in a salt marsh were experimentally investigated by

chronic fertilization of plots. All nutrient enrichments (urea, three dosages of a mixed fertilizer) resulted in increased grass standing crop of low and high marsh habitat. Plant nitrogen content increased only in those plots receiving the two highest levels of mixed fertilizer. Grass responses were most rapid where the highest nutrient load was applied.

In all plots, fertilization resulted in increased standing crop of low and high marsh insect herbivores. However, the greatest herbivore loads occurred where grass nitrogen content as well as standing crop had increased. Life history data and laboratory experiments indicated that the herbivore increases were largely due to in situ changes in survivorship and fecundity in response to higher plant nitrogen content. The herbivore response to fertilization was rapid, tracking in a single summer the nutrient biomass changes of the grasses. The rate of increase, however, varied among herbivore species according to the annual number of generations and overwintering stage.

Nutrient additions did not alter the diversity of the high marsh herbivore community, but led to increased diversity in low marsh. This was achieved primarily by greater equitability of the species abundances. All of the herbivore species collected in the fertilized plots were common to the undisturbed salt marsh. The low marsh herbivore community responded to fertilization mainly with greater numbers of mirids, cicadellids, and grasshoppers, although normally highly dominated by the delphacid *Prokelisia marginata*. Potential increases in number of *P. marginata* in response to fertilization were apparently checked by the increased abundance of spiders. The impact of spider predation was especially severe on the delphacids, due both to size selection by the predators and habitat selection by the prey. Plant nutritional quality is of major importance in governing the abundance of salt marsh herbivores, with life history characteristics and predation interacting to structure the community.

Supported by: National Science Foundation Grant #OCE74-12743A01 and the Victoria Foundation.

## Z O O P L A N K T O N

IMPACT OF POWER PLANT DISCHARGES ON MARINE  
ZOOPLANKTON: A REVIEW OF THERMAL,  
MECHANICAL AND BIOCIDAL EFFECTS

Judith M. Capuzzo

The relative importance of thermal, mechanical and biocidal stresses to marine zooplankton entrained in cooling waters from coastal power plant operations is dependent on specific features of power plant design and siting. Toxic effects of power plant operations will vary with (1) the degree of mechanical stress induced by pumping velocities of cooling water; (2) the physical and chemical interaction of receiving and discharge waters; (3) the dosage of chlorine or other biocide added to cooling waters for fouling control; (4) the exposure time to stress conditions experienced during passage through condenser conduits and discharge canals; and (5) the nature of receiving waters, affecting the production and availability of the various halogen toxicants formed upon chlorination of seawater.

Because of these variables, the problem of entrainment induced mortality of zooplankton and the resulting effects on secondary production in receiving waters is difficult to assess. A review of laboratory and field studies addressing these problems is presented and particular emphasis given to the synergistic effect of multiple stresses.

In Press: Helgolander wiss. Meeresunters. Presented at 14th European Marine Biology Symposium - Helgoland.

Supported by: Energy Research and Development Administration Contract #E(11-1)-2532.

VERTICAL DISTRIBUTION AND ISOTOPIC  
COMPOSITION OF LIVING PLANKTONIC  
FORAMINIFERA IN THE WESTERN NORTH ATLANTICRichard Fairbanks, Peter Wiebe  
and Allen Be

Thirteen species of planktonic foraminifera collected with vertically stratified zooplankton tows in the slope water, Gulf Stream cold core ring, and northern Sargasso Sea show significant differences in their vertical distribution in the upper 200 meters of these different hydrographic regimes. Gulf Stream cold core rings may be responsible for a southern displacement

of the faunal boundary associated with the Gulf Stream when reconstructed from the deep-sea sediment record. Oxygen isotope analyses of seven species reveal that non-spinose species (algal symbiont-barren) apparently calcify in oxygen isotope equilibrium, whereas spinose species usually calcify out of oxygen isotope equilibrium by approximately -0.3 to -0.4 per mil in  $\delta^{18}O$  values. The isotope data indicate that foraminifera shells calcify in depth zones that are significantly narrower than the overall vertical distribution of a species would imply.

Published in: Science.

Supported by: National Science Foundation Grant #OCE-7725976 and Office of Naval Research Contract Numbers N00014-66-CO241, NR083-004 and N00014-74-CO262 NR083-004.

FORAMINIFERA AND THE CHLOROPHYLL MAXIMUM:  
A MODEL OF SPECIES VERTICAL DISTRIBUTION  
AND SEASONAL SUCCESSION

Richard G. Fairbanks and Peter H. Wiebe

Water temperature at the depth of the chlorophyll maximum is a key indicator of planktonic foraminifera species composition and seasonal succession. The chlorophyll maximum is where many foraminiferal species are depositing their shells and it is the temperature at the chlorophyll maximum which is relevant to oceanographic models which use  $^{18}O/^{16}O$  ratios in fossil foraminifera and foraminifera fossil assemblages to predict past climates. During periods of stratification of the upper water column, the temperature at the chlorophyll maximum may differ from the sea surface temperature by 10°C in the Western North Atlantic.

Supported by: National Science Foundation Grant Numbers OCE-7725976, DES 74-02783A01; and Office of Naval Research Contract #N00014-74-CO262 NR 083-004.

AN APPARATUS FOR THE MEASUREMENT OF  
GRAZING ACTIVITY OF FILTER FEEDERS AT  
CONSTANT FOOD CONCENTRATIONS

Scott M. Gallager and Roger Mann

An apparatus is described which measures the grazing activity of filter feeding invertebrate larvae and adults in an environment in which the phytoplankton food concentration can be maintained at a constant level. The "sensing" portion of the

apparatus consists of a Model III Turner fluorometer equipped with a modified flow through door. Sensitivities of  $\pm 1\%$  of a selected phytoplankton concentration were achieved in experiments in which the flagellate Isochrysis galbana was fed to larvae of the bivalve Teredo navalis, the gastropod Aplysia californica, and adults of the copepod Acartia tonsa. The apparatus can be effectively used with as few as 100 mollusc larvae.

Supported by: Office of Naval Research  
Contract #N00014-79-C0071 NR 083-004.

ZOOPLANKTON INVESTIGATIONS IN GULF WATERS  
NORTH AND SOUTH OF THE STRAITS OF HORMOZ

Victoria R. Gibson, George D. Grice and  
Stephen J. Graham

Quantitative zooplankton (23 samples) and neuston (34 samples) collections were made throughout the Gulf north of the Straits of Hormoz and at several places in the Gulf of Oman in spring 1977. Zooplankton biomass in the oblique tows ranged from .11 to 2.00 cc/m<sup>3</sup> and .52 to 2.27 cc/m<sup>3</sup> in the waters respectively north and south of the Straits. Significantly higher volumes were recorded from the Gulf of Oman. The numerical abundance of zooplankton varied from 79 to 5098/m<sup>3</sup>. Copepods comprised more than 50% of the zooplankton in over one-half of the collections. The highest zooplankton volumes occurred in the central area and there were no significant differences in the quantities of zooplankton between day and night. Thirteen species of pontellid copepods were identified in neuston samples, including eight species that represent new records.

In Press: Symposium on the Coastal and Marine Environment of the Red Sea, Gulf of Aden and Tropical Western Indian Ocean; Khartoum, Sept. 15-20, 1979.

Supported by: Iranian Department of the Environment.

LARGE SCALE ENCLOSED WATER COLUMN  
ECOSYSTEMS: AN OVERVIEW OF FOODWEB I,  
THE LAST CEPEX EXPERIMENT

George D. Grice, Roger P. Harris,  
Michael R. Reeve, John F. Heinbokel  
and Curtiss O. Davis

FOODWEB I was an experiment on natural unpolluted planktonic populations, captured and maintained in large (1,300 m<sup>-3</sup>) enclosures, which was designed to compare

differences in the structure and efficiency of food chains based on diatoms and flagellates as primary producers. By observing and quantifying subsequent changes in the two food chains leading to young fish we hoped to examine experimentally some recent hypothesis concerning control of the structure of pelagic ecosystems. Although diatom and flagellate assemblages were successfully established and maintained in the enclosures through selective nutrient additions and mixing regimes, a large number of ctenophores developed, and effectively eliminated the herbivorous copepods within 40 days. Although the experiment lasted for 111 days, residual ctenophores did not permit the copepods to recover sufficiently to develop identifiable responses to the two phytoplankton communities. In spite of this, a large mass of data were accumulated on the numerical abundance and carbon biomass of the populations including bacteria, phytoplankton, ciliates, larvaceans, copepods and ctenophores. We discuss the utility of the controlled ecosystem approach as a third method of studying natural planktonic ecosystems, intermediate between small-scale laboratory studies and conventional field investigations.

In Press: Journal Marine Biological Association U.K.

Supported by: National Science Foundation Grant #OCE77-27906.

FACT AND ARTIFACT IN COPEPOD FEEDING  
EXPERIMENTS

G. Richard Harbison and Vicki L. McAlister

We question the results of several recent papers on selective feeding by copepods on particles in natural seawater because: (1) the Coulter Counter is used to size particles, and the equivalent spherical diameters it gives bear little relationship to the actual dimensions of many algal cells; (2) sieves remove particles from water on the basis of their linear dimensions, not necessarily on the basis of their volumes; and (3) some algal cells are broken by gentle agitation. At present, it is impossible to do proper control experiments to evaluate the contribution of these sources of artifact to experimental results.

Supported by: National Science Foundation Grant #OCE77-22511.

OCEANIC ZOOPLANKTON: DISTRIBUTION IN  
FINE-SCALE MULTISPECIES AGGREGATIONS

Loren R. Haury and Peter H. Wiebe

Sixteen Longhurst-Hardy Plankton Recorder tows were taken in the Northwest Atlantic for analysis of fine-scale horizontal patchiness. Abundant species were non-randomly distributed in patches with scales of tens to hundreds of meters. Positive correlations between species abundances dominated, indicating that the patches were multispecies associations. Most horizontal pattern appeared to be of biological origin.

Supported by: National Science Foundation Grant #OCE-209132 and by the Marine Life Research Program of the Scripps Institution of Oceanography.

ON THE POPULATION BIOLOGY AND NATURE OF  
DIAPAUSE OF LABIDOCERA AESTIVA  
(COPEPODA: CALANOIDA)

Nancy H. Marcus

The calanoid copepod, Labidocera aestiva was collected from Vineyard Sound, MA between July and December 1978. Adult size (cephalothorax and total body length) was inversely proportional to surface water temperature at the time of collection. The major switch from subitaneous to resting egg production occurred during late August-early September, but a small percent of subitaneous eggs continued to be produced throughout the fall. Resting eggs were cold-resistant and when chilled at 5°C hatched synchronously when warmed to 21°-23°C. Individual resting eggs kept continuously at 19°C took longer to hatch and emergence was asynchronous. The resting eggs of L. aestiva to be in a state of diapause similar to many insects, and it is suggested that photoperiod is the primary cue inducing the production of resting eggs.

Published in: Biological Bulletin  
Vol. 157, pp. 297-305.

Supported by: National Science Foundation Grant #OCE-7808857 and the Ocean Industry Program of the Woods Hole Oceanographic Institution.

THE ECOLOGY OF COLLOZOU LONGIFORME, SP.  
NOV., A NEW COLONIAL RADIOLARIAN FROM THE  
EQUATORIAL ATLANTIC OCEAN

Neil R. Swanberg and G. Richard Harbison

A new species of colonial radiolarian (Collozoum longiforme) is described from the equatorial Atlantic Ocean. It forms elongate colonies (up to 3 m long). The carbon mass of the colony relates well with the density of central capsules; the number of algal cells per central capsule is relatively constant. Incorporation of <sup>14</sup>C per unit chlorophyll a is largely independent of light intensity, and is most strongly affected by the feeding history of the predatory radiolarian cells. Radiolarians feed on a wide variety of planktonic organisms, as determined by remains found in the colony matrix; remains of tintinnids predominate. Colonies serve as hosts for several hyperiid amphipods and the harpacticoid copepod Miracia efferata. Collozoum longiforme has been found only in oligotrophic equatorial Atlantic waters, and the colonies may serve as largely self-contained islands in the open ocean ecosystem.

In Press: Deep Sea Research.

Supported by: WHOI Education Program;  
National Science Foundation Grant  
Numbers OCE75-21715 and OCE77-22511.

# CHEMISTRY

DEPARTMENT OF CHEMISTRY  
Geoffrey Thompson, Chairman

## RADIOCHEMISTRY

LEAD-210, POLONIUM-210,  
MANGANESE AND IRON IN THE CARIACO TRENCH

Michael P. Bacon, Peter G. Brewer,  
Derek W. Spencer,  
James W. Murray and John Goddard

Measurements of temperature, salinity, dissolved oxygen, sulfide,  $^{226}\text{Ra}$ , Mn, Fe,  $^{210}\text{Pb}$ ,  $^{210}\text{Po}$ , and total suspended matter from three cruises of R/V Atlantis II in the Cariaco Trench are reported. Distributions of dissolved and particulate Mn and Fe are similar to those for the Black Sea and reflect similar diffusion and redox-potential controls.

Results for  $^{210}\text{Pb}$  and  $^{226}\text{Ra}$  in the anoxic deep water indicate a residence time for  $^{210}\text{Pb}$  in solution of less than 2 years. Particulate  $^{210}\text{Pb}$  results suggest that removal occurs largely by incorporation into metal sulfide phases forming in the water column. There is also evidence for precipitation of  $^{210}\text{Pb}$  with manganese oxide or iron hydroxide just above the  $\text{O}_2\text{-H}_2\text{S}$  interface. In the upper 300 m,  $^{210}\text{Po}$  is enriched by 55% over radioactive equilibrium with  $^{210}\text{Pb}$ . Possible sources of this excess include the bottom sediments and the water upwelling along the Venezuelan coast.

Published in: Deep-Sea Research  
(in press).

Supported by: Department of Energy  
Contract EY-76-S-02-3566.

$^{210}\text{Pb}$  AND  $^{210}\text{Po}$   
ENRICHMENT OF  
IN THE SEA-SURFACE MICROLAYER

Michael P. Bacon and Alan W. Elzerman

Samples of the sea-surface microlayer collected by the screen technique from Vineyard Sound, Massachusetts, and from the open North Atlantic Ocean were found to be enriched in  $^{210}\text{Pb}$  and  $^{210}\text{Po}$  by factors ranging from 1.2 to 12.9 relative to bulk surface seawater. A sample of foam from a coastal pond was enriched in both nuclides by a factor of about 40. Model calculations in which the enrichment is considered to derive from an atmospheric component and a fractionated marine component suggest that a significant percentage of the enrichment is maintained by concentration from the bulk surface seawater with preferential transport of  $^{210}\text{Po}$  to the air-sea interface.

Supported by: Department of Energy  
Contract EY-76-02-3566; Postdoctoral  
Award to A.W. Elzerman.

A SEDIMENT TRAP EXPERIMENT  
IN THE DEEP SUB-TROPICAL ATLANTIC:  
ISOTOPIC AND ELEMENTAL FLUXES

Peter G. Brewer, Yoshiyuki Nozaki,  
Derek W. Spencer and Alan P. Floor

We have carried out sediment trap experiments at sites in the Sargasso Sea ( $S_2$ ) and in the Atlantic off Barbados (E) to determine the mass flux and chemical composition of material sinking to the sea floor. At the  $S_2$  site the mass flux increases with depth from 280-740  $\mu\text{g cm}^{-2} \text{yr}^{-1}$ ; at the E site the flux is constant at 1800  $\mu\text{g cm}^{-2} \text{yr}^{-1}$ . Chemical analyses show that K, Ti, Al, La, V, Co and  $^{232}\text{Th}$  are derived largely from terrigenous material whereas Ca, Sr, Mg, Si, Ba,  $^{226}\text{Ra}$ , U and I are carried by biogenic particles. The reactive elements Mn, Cu, Fe, Sc and  $^{230,234}\text{Th}$ , show increasing ratios to Al with depth due to scavenging from the water column. We calculate a mean particle settling velocity of 21  $\text{m/day}^{-1}$  and scavenging residence times ranging from 22 years for Th to 770 years for Cu. The flux of aluminosilicates increases with depth, and this cannot be attributed to changes in trap efficiency. Thus horizontal transport of material must be invoked.

Supported by: National Science Foundation Grant OCE 77-27004 and Department of Energy Contract EY-76-S-02-3566 to WHOI and National Science Foundation Grant OCE 76-20239 to Yale University (Y. Nozaki's support), K. K. Turekian, Principal Investigator.

HELIUM ISOTOPE LABORATORY  
DATA RELEASE NO. 1

William J. Jenkins,  
William V. Collentro and  
Richard D. Boudreau

This report summarizes technique, estimated precisions and results for  $^3\text{H}$  and  $^3\text{He}$  analyses made on three cruises in the Sargasso Sea. In addition, a statistical treatment is made on 36 surface ( $\approx 10 \text{ m}$ )  $^3\text{He}/^4\text{He}$  analyses to obtain an estimate of the solubility isotope effect and its temperature dependence to be

$$(\alpha - 1) \times 1000 \text{‰} = -(17.3 \pm 0.8) \\ + (0.38 \pm 0.06) T \text{ (}^\circ\text{C)}$$

with a regression scatter of 2.6‰ and a linear correlation coefficient of 0.940.

Published in: WHOI Technical Report  
79-60, July 1979.

Supported by: NSF Grant OCE 76-81774.

TRITIUM IN THE DEEP NORTH ATLANTIC OCEAN

William J. Jenkins and Peter B. Rhines

A distinct core of tritium (from atmospheric nuclear weapons testing) marks the southward flowing jet of the deep western boundary current of the North Atlantic circulation of 30°N latitude. The concentrations, ca. 0.5 to 1.0 T.U., indicate a roughly ten-fold dilution of source waters north of the Grand Banks.

Supported by: ONR Contract N00014-776-C-0197, NR 083-400 and National Science Foundation Grants OCE 76-81774 and OCE 76-81190.

MASS SPECTROMETRIC MEASUREMENTOF TRITIUM AND  $^3\text{He}$ 

William J. Jenkins

The techniques of mass spectrometric helium isotopic analysis and low-level tritium measurement by  $^3\text{He}$  regrowth are described and discussed in light of analytical precision and standardization accuracy. In addition, the helium isotope effect in solution in seawater is determined as a function of temperature from -2°C to +25°C for the salinity range 32‰ to 38‰.

Published in: Proceedings of I.A.E.A. Vienna, 1979.

Supported by: National Science Foundation Grant OCE 76-81774.

TRITIUM AND  $^3\text{He}$  IN THE SARGASSO SEA

William J. Jenkins

The systematics of tritium ( $^3\text{H}$ ),  $^3\text{He}$  and  $^3\text{H}$ - $^3\text{He}$  dating are investigated for oceanic mixing systems responding to the North Atlantic surface water tritium transient. Although the  $^3\text{H}$ - $^3\text{He}$  age is a single valued function of the "true" mixing age, verbatim acceptance of the  $^3\text{H}$ - $^3\text{He}$  age will result in a substantial underestimate of the mixing age for systems with timescales approaching the time elapsed since the tritium transient (1964-1965) or greater.  $^3\text{H}$ - $^3\text{He}$  data are presented for a number of stations taken recently in the Sargasso Sea and discussed qualitatively. Most remarkable are the  $^3\text{H}$  and  $^3\text{He}$  maxima associated with subtropical mode water and the density stratum usually

associated with Mediterranean water. Preliminary evidence indicates that this latter water type is not necessarily of direct Mediterranean water origin, and model calculations indicate that an intermediate level flux of as much as 1.0 Sv may be required to explain this feature. However this feature may also be explained by lateral circulation.

It is demonstrated that the penetration of tritium into and generation of  $^3\text{He}$  within the subtropical North Atlantic main thermocline cannot be explained on the basis of a purely vertical transport model. Comparison of the vertical diagnostic model results for tritium with other estimates of the vertical diffusivity suggests that vertical processes contribute less than ten percent to the mass balance of the thermocline. A simple, lateral mixing model is proposed which satisfactorily explains both the  $^3\text{H}$  and  $^3\text{He}$  distributions and their evolution in time. Although the exclusion of vertical diffusion as the major transport process rules out a number of thermocline models, this simple model is consistent with thermocline models incorporating isopycnal transport. A characteristic ventilation time for the main thermocline in the Sargasso Sea is estimated to be of the order of 50 y, while the oxygen minimum layer is characterized by a ventilation time in excess of seventy years.

Oxygen utilization rates are obtained for the upper 2 km, and are seen to decrease from a near-surface value of 0.5 ml/l/y to .004 ml/l/y at 1800 m, with an e-folding depth of the order of 350 m.

Supported by: National Science Foundation Grant OCE 76-81774.

A PROCEDURE FOR INDEPENDENTLY ESTIMATING  
BLANKS AND UNCERTAINTIES FOR MEASURED  
VALUES OF  $^{90}\text{Sr}$  AND  $^{137}\text{Cs}$  IN THE  
ATLANTIC OCEAN

Stuart L. Kupferman and Hugh D. Livingston

A procedure has been developed for independently estimating blanks and measurement uncertainties for measured values of  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  concentrations in the Atlantic Ocean. The procedure depends on delineation of a region in the Atlantic Ocean which has never contained measurable quantities of these fission products. Such a region is defined. A simple model, with supporting data, is used to show that reported  $^{137}\text{Cs}$  inventories in deep ocean sediments could have accumulated without over-raising concentrations of  $^{137}\text{Cs}$  in this tracer-free volume above minimum detectable

limits. Several examples are presented to show that the use of the procedure results in a substantial improvement in the quality of  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  data. The method is applicable to any laboratory that has determined  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  concentrations in samples collected from within the tracer-free volume.

Published in: *Journal of Marine Research*, Vol. 37, 1, 1979.

Supported by: U.S. Department of Energy Contract EY-76-S-02-3563 and the National Science Foundation Grant OCE 75-23434.

A MASS BALANCE FOR  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$   
IN THE NORTH ATLANTIC OCEAN

Stuart L. Kupferman, Hugh D. Livingston  
and Vaughan T. Bowen

The total inventory of  $^{137}\text{Cs}$  (3,722 kCi) and  $^{90}\text{Sr}$  (2,257 kCi) in the North Atlantic Ocean in 1972, as well as the sub-inventories in the 0 to 1000 m, 1000 to 2000 m, 2000 m to bottom layers, continental shelf waters and bottom sediments have been estimated. We have been careful to provide reliable estimates of uncertainty for each of these values. We have also estimated the inputs of  $^{137}\text{Cs}$  to the Atlantic Ocean as direct fallout (2065 kCi), or as ocean current transport (240 kCi) since the start of large scale nuclear testing. The inputs are 20 to 30% less than the total inventory. We believe that the input has been underestimated by use of the traditional assumption that the mean fallout rates in  $10^\circ$  latitude bands are the same over the ocean as measured on land by the fallout in precipitation network. We have estimated the uncertainties inherent in using land data and find that the difference is not irreconcilable.

25% of the  $^{137}\text{Cs}$  in the North Atlantic is found beneath the 1000 m level. If it is assumed that water, once it sinks below the 1000 m level, is not returned within decades to the surface, then based on estimates of the  $^{137}\text{Cs}$  concentration in northern near surface waters between 1952 and 1972, the mean sinking rate of near surface water below the 1000 m level for the 20 years prior to 1972 must have been close to  $14 \times 10^6 \text{ m}^3/\text{s}$ .

Published in: *Journal of Marine Research*, 37, 1, 1979.

Supported by: U. S. Department of Energy Contract EY-76-S-02-3563 and the National Science Foundation Grant OCE 75-23434.

$^{137}\text{Cs}$  AND  $^{239,240}\text{Pu}$  IN COASTAL SEDIMENTS

Hugh D. Livingston and Vaughan T. Bowen

Analyses are presented of  $^{137}\text{Cs}$ ,  $^{238}\text{Pu}$ , and  $^{239,240}\text{Pu}$  in relation to depth in sediment, in 21 gravity cores. These cores span the ranges of times 1964 to 1972, and of water depths 12 to 2000 m; they come from three distinct sedimentation areas on the northeast coast of the United States. Although the ranges of total sediment inventories of  $^{239,240}\text{Pu}$  and of  $^{137}\text{Cs}$  from the various areas hardly overlap, the range of ratios of the inventories of these radionuclides is probably the same in all the areas. In the shallow water cores the ratio  $^{239,240}\text{Pu}$  to  $^{137}\text{Cs}$  regularly diminishes with depth in the cores, and a tendency is seen for curves of this function to have similar slopes in each area; ratios of  $^{238}\text{Pu}$  to  $^{239,240}\text{Pu}$  show no change with depth in these shallow water cores. In the deeper water cores, the ratio  $^{239,240}\text{Pu}$  to  $^{137}\text{Cs}$  shows no systematic change with depth, but sometimes the ratio  $^{238}\text{Pu}$  to  $^{239,240}\text{Pu}$  shows a minimum at the sediment surface, and is much higher deeper in the cores. We believe that these phenomena can be explained in terms of a complicated perturbational process moving the radionuclides, together, down into the sediments, or chemical resolubilization, at depth, of Pu only, and of its subsequent upward translocation in the interstitial solution. Some re-immobilization of Pu near the sediment surface is implied, and a mechanism is suggested for this, based on displacement of Pu from organic complexes by the increasing concentrations, in upper layers of the sediment, of re-oxidized dissolved iron.

Published in: *Earth and Planetary Science Letters*, 43: (1979) 29-45.

Supported by: Department of Energy Contract EY-76-S-02-3563 and EY-76-02-2379.

CONTROLS ON PORE FLUID CONCENTRATION  
AND VARIATIONS IN

$^4\text{He}/^{222}\text{Rn}$  AND  $^4\text{He}/^{222}\text{Rn}$  RATIOS

Thomas Torgersen

The use of  $^4\text{He}$  and  $^{222}\text{Rn}$  measurements in pore fluids is discussed in terms of the mechanisms which control their release from the solid phase to the pore fluid. Three mechanisms are discussed (1) recoil path length control (2) rapid diffusion at grain boundaries and tracks, and (3) weathering release.

The use of accumulated  $^4\text{He}$  as a pore fluid dating tool is evaluated in terms of the  $^4\text{He}/^{222}\text{Rn}$  ratio.  $^{222}\text{Rn}$  activity is used to quantify the production rate and results in a simplified age equation. Data from gas wells, cold springs and geothermal wells are presented and discussed in terms of the controlling mechanisms.

Supported by: U.S. Geological Survey  
Grant 14-08-0001-G-541.

ISOTOPIIC COMPOSITION OF RIVER RUNOFF  
ON THE U.S. EAST COAST:  
EVALUATION OF STABLE ISOTOPE  
vs. SALINITY PLOTS  
FOR COASTAL WATER MASS IDENTIFICATION

Thomas Torgersen

$\delta\text{D}$  and some  $\delta^{18}\text{O}$  measurements were made on thirty-six rivers which drain the East Coast of the U.S. The data are consistent with the work of Friedman et al., 1964. The streamflow data of Bue (1970) were used to estimate the mean isotopic composition of runoff entering (1) the Gulf of Maine, (2) the mid-Atlantic Bight and (3) the South Atlantic Bight. Assuming binary mixing between central Atlantic water and these fresh runoff waters, coastal water in the Gulf of Maine is isotopically indistinguishable from runoff into the mid-Atlantic Bight and runoff from the St. Lawrence at salinities greater than 32‰. However, up to salinities of 34‰, the mean isotopic composition of runoff into the South Atlantic Bight is sufficiently different from the mid-Atlantic Bight that identification of coastal water masses in and around Cape Hatteras by  $\delta\text{D}$  and/or  $\delta^{18}\text{O}$  vs. salinity plots should be possible.

Supported by: Department of Energy Contract E-2185 (Lamont-Doherty) and National Science Foundation Grant OCE 76-81774.

CONTROLS ON PORE FLUID CONCENTRATION  
OF  $^4\text{He}$  AND  $^{222}\text{Rn}$  AND THE CALCULATION  
OF  $^4\text{He}/^{222}\text{Rn}$  AGES

Thomas Torgersen

The use of accumulated  $^4\text{He}$  in pore fluids as a groundwater dating tool is evaluated.  $^{222}\text{Rn}$  activity is used to quantify the production rate and results in a simplified age equation. The dependent term in the model age equation is the  $^4\text{He}/^{222}\text{Rn}$  ratio and an independent term which at present can only loosely constrain.

The method is applied to deep-sea basement porewater and gives good agreement with known sediment parameters. For cold springs and geothermal well gases, however, the model age is much too large due to the addition of trapped helium by chemical weathering of rock grains. It is concluded, therefore, that as an absolute pore fluid dating method, accumulated  $^4\text{He}$  does not present a simple case for age determinations. The  $^4\text{He}/^{222}\text{Rn}$  ratio, however, does contain significant hydrologic information.

Supported by: U.S. Geological Survey  
Grant 14-08-0001-G-541.

FAYETTEVILLE, GREEN LAKE, N. Y.:

$^3\text{H}$ - $^3\text{He}$  WATER MASS AGES  
AND SECONDARY CHEMICAL STRUCTURE

Thomas Torgersen, D. E. Hammond,  
W. Brian Clarke and T. H. Peng

New chemical and isotopic measurements in Green Lake are reported. Chemistry and helium isotope profiles give evidence for a "secondary chemocline" at  $\approx 32.5$  m.  $^{222}\text{Rn}$  and  $^{14}\text{C}$  profiles indicate the position of at least two groundwater sources, the dominant one being at  $\approx 20$  m. New  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  measurements are found to be inconsistent with the two-box model of Takemashi et al. (1968).  $^3\text{H}$  and tritiogenic  $^3\text{He}$  are used to determine the water mass ages and a mean age of 4.96 years is obtained for the upper monimolimnion (16-32.5 m) and 8.72 years for the lower monimolimnion (32.5-57 m). From this time constraint, it is calculated that diffusion from the sediments could account for a substantial fraction of the additional  $\text{Cl}^-$  and  $\text{Na}^+$  present below the "secondary chemocline".

Supported by: National Science Foundation Grant OCE 76-81774 and Lamont-Doherty Geological Observatory GB36348 and GA33124.

## SEAWATER CHEMISTRY

DETERMINATION OF BARIUM IN SEAWATER BY A STANDARD ADDITION METHOD ADAPTED TO THE DIRECT CURRENT ECHELLE OPTICAL EMISSION SPECTROMETER

Donald C. Bankston

A technique for determining trace concentrations of barium in seawater is described. Analyses are performed using an optical emission spectrometer/spectrograph equipped with an echelle monochromator and a dc argon plasma excitation source. Calibration is done by the addition method. Three portions of each sample are used for each determination. Each of these is mixed in a 9:1 volumetric ratio with a solution containing 2% (w/v) lithium and either 0, 200, or 400 g of barium per liter. The instrumental response to 0 g of barium per liter is estimated using a 0.2% (w/v) solution of lithium in deionized distilled water as a blank. The accuracy of results obtained in this study is assessed by comparing them with replicate data previously obtained by another investigator using isotope dilution mass spectrometry. The detection limit of the present method is  $\sim 2 \mu\text{g/l}$ . Near this limit, the RSD ranged from 13 to 27%.

Published in: Proceedings of the International Winter Conference APSO, San Juan, Puerto Rico.

Supported by: Department of Energy Contract EY-76-C-02-3563.

SEASONAL CHANGE IN THE FLUX OF ORGANIC CARBON TO THE DEEP SARGASSO SEA

Werner G. Deuser and Edith H. Ross

Between April 1978 and July 1979 a series of samples of particulate matter was collected in a sediment trap moored 25 miles southeast of Bermuda, 3200 m below the sea surface and 1000 m above the sea floor. Collection periods ranged from 60 to 68 days. The amounts collected per unit time varied by a factor of 2.75, with highs in April/May and lows in the summer months. Organic carbon varied in the same way. The changes appear to be related to seasonal changes in the primary productivity of the surface water. One percent of the net production of carbon at the surface penetrated beyond 3000 m. These results point towards a possible link between seasonality of surface productivity and seasonal breeding and growth cycles in deep sea organisms.

Published in: Nature (in press).

Supported by: National Science Foundation Grants OCE 76-21280 and OCE 78-19813.

REDUCTION OF MATRIX EFFECTS IN THE CARBON FURNACE ATOMIC ABSORPTION SPECTROMETRIC ANALYSIS OF COBALT, COPPER AND MANGANESE IN SEAWATER USING A SOLUBLE ORGANIC ACID

David J. Hydes

Addition of 1% (w/v) ascorbic acid to sea water reduces interferences observed in direct injection measurements of Cu and eliminates interferences occurring in Co and Mn determinations. Stability of the analyte on the surface of the atomizer tube, with respect to increasing temperature, is restored to that in a 0.1 N HCl matrix. In sodium chloride solution, interference with Mn and Cu measurements probably results from atomization of Mn and Cu chlorides, and formation of non-absorbing monochlorides in the vapor phase. In sea water, the mechanism producing interference cannot presently be explained.

Supported by: National Science Foundation Grant OCE 78-8895.

ALUMINUM IN SEAWATER: CONTROL BY INORGANIC PROCESSES

David J. Hydes

The distribution of dissolved aluminum in open ocean waters is probably controlled by solution of aluminum from atmospherically derived particles and bottom sediments balanced by scavenging by siliceous tests of dead organisms. Variations in concentration within vertical hydrographic profiles are small compared to those for other trace metals. Concentrations in the Atlantic and Pacific are inversely related to the silica content of these oceans.

Supported by: National Science Foundation Grant OCE 78-10277.

ON THE CLIMATOLOGY OF AN OCEANIC SUBTROPICAL GYRE

William J. Jenkins

Significant and coherent variations on decade timescales are seen in the salinity associated with certain density strata at a hydrographic station north of Bermuda. These variations are shown to covary at a statistically significant level with other climatic

and meteorological parameters, and in a fashion which is consistent with the hypothesis that this salinity variability is driven by variations in the intensity of water mass formation.

Supported by: National Science Foundation Grant OCE 76-81774.

WIND STRESS DIRECTION AND THE ALONGSHORE  
PRESSURE GRADIENT  
IN THE MIDDLE ATLANTIC BIGHT

Kathryn Bush and Stuart L. Kupferman

We find that the alongshore transport in winter calculated using a circulation model based on Ekman and geostrophic dynamics (Csanady, 1976) for a shelf region similar to the Middle Atlantic Bight is sensitive to the alongshore component of the wind stress and to the alongshore pressure gradient. If the total alongshore transport in the region remains uniform along the shelf at  $2.5 \times 10^5 \text{ m}^3/\text{s}$  (positive poleward) as indicated by current meter measurements, our calculations show that the alongshore pressure gradient must decrease from  $1 \times 10^{-3} \text{ Pa/m}$  off Montauk Point to zero south of Cape Henry, as a consequence of the change in orientation of shelf to wind stress.

Published in: Journal of Physical Oceanography, March 1980 (in press).

Supported by: Department of Energy Contract EY-76-S-02-3563.

FERRIC DI AND TRIHYDROXY COMPLEXES  
IN SEAWATER

Oliver C. Zafiriou and Mary B. True

Interconversion rates of the mononuclear ferric iron species  $\text{Fe}(\text{OH})_3^0$  and  $\text{Fe}(\text{OH})_2^+$  are derived and their implications for the behavior of these species in seawater are examined. The previously reported formation constant for  $\text{Fe}(\text{OH})_3^0$  and its claimed extreme adsorptive reactivity in seawater are shown to be mutually inconsistent. Although  $\text{Fe}(\text{OH})_3^0$  is probably a stoichiometrically minor dissolved iron species, its rapid formation from  $\text{Fe}(\text{OH})_2^+$  could substantially enhance the rates of heterogeneous reactions of the  $(\text{Fe}(\text{OH})_2^+ + \text{Fe}(\text{OH})_3^0)$  pool if the latter species is very reactive.

Published in: Marine Chemistry, 1979.

Supported by: National Science Foundation Grant OCE 76-08696.

NITRIC OXIDE IN SEAWATER

Oliver C. Zafiriou, Mack McFarland  
and Richard H. Bromund

Nitrite photolysis at natural light intensities and nitrite levels in seawater produced detectable levels of nitric oxide (NO), which was consumed rapidly by a dark chemical reaction in the laboratory. Nitric oxide was also detected *in situ* in nitrite-rich surface waters of the central equatorial Pacific, where it formed in daylight and disappeared rapidly at sunset. The formation and rapid cycling of nitric oxide implies the presence of other free radicals in seawater, perhaps as intermediates in on-going autoxidation processes. The central equatorial Pacific is a nitric oxide source to the atmosphere.

Supported by: National Science Foundation Grants OCE 76-08696 and ATM 78-00997.

WET AND DRY REMOVAL OF TROPOSPHERIC  
FORMALDEHYDE AT A COASTAL SITE

Anne Mee Thompson

Formaldehyde in precipitation and in surface seawater has been measured at Woods Hole, Massachusetts (U.S.A.) a mid-latitude coastal site. From these measurements and a calculation of the diffusion-controlled air-to-sea transfer rate of the compound we estimate the wet and dry flux of  $\text{H}_2\text{CO}$  from the troposphere to nearby coastal waters to be  $6.3 \mu\text{g cm}^{-2} \text{ yr}^{-1}$  for precipitation and  $5.7 \mu\text{g cm}^{-2} \text{ yr}^{-1}$  for gaseous diffusion. A comparison of these values with a simple photochemical model shows that these transfers may represent a significant removal mechanism for tropospheric formaldehyde.

The total flux of  $\text{H}_2\text{CO}$  is equivalent to an input of  $4.8 \mu\text{g cm}^{-2} \text{ yr}^{-1}$ , organic carbon,  $\geq 1\%$  of estimated total organic carbon air-to-sea transfer. The absence of a detectable amount of formaldehyde in surface seawater suggests that its fate might be biological uptake. This view is supported by the finding that seawater enriched with formaldehyde shows a gradual loss of the compound, whereas the level remains unchanged in sterile seawater under light and dark conditions.

Supported by: WHOI Post-Doctoral Fellowship; National Science Foundation Grant OCE 77-12914.

A SEQUENCING SEDIMENT TRAP FOR  
TIME-SERIES STUDIES OF FRAGILE PARTICLES

Hans W. Jannasch, Oliver C. Zatiriou  
and John W. Farrington

A versatile sediment trap for time-series studies has been developed and tested by deployments in Buzzards Bay, Massachusetts and at 600 atm pressure. It collects up to eight samples at widely variable intervals, preserves them if desired in a viscous aqueous medium, and can be redeployed rapidly.

Supported by: ONR Contract N00014-74-CO-262 NR 083-004 and National Science Foundation Grant OCE 74-22781.

FORMALDEHYDE IN REMOTE MARINE AIR AND RAIN:  
FLUX MEASUREMENTS AND ESTIMATES

Oliver C. Zatiriou, Jane Allora,  
Michelle Herrera,  
Edward T. Peltzer, Anne Mee Thompson,  
Robert B. Gagosian and S. C. Liu

The tropospheric trace constituent formaldehyde, HCHO, was measured in rain and in the gas phase during the wet season at Enewetak Atoll, a remote marine site in the central equatorial Pacific. Rainwater averaged  $8 \pm 2$   $\mu\text{g}/\text{kg}$ ; the gas phase averaged  $0.4 \pm 0.2$  ppbv ( $0.5$   $\mu\text{g}/\text{m}^3$ ). These values, especially the rain, are among the lowest reported to date. The formaldehyde flux to the sea by rainout and washout extrapolates to  $0.010$   $\text{g}/\text{m}^2/\text{yr}$ . The gaseous flux into the sea surface is estimated to be  $0.04$   $\text{g}/\text{m}^2/\text{yr}$  by an air-sea exchange calculation that takes into account enhanced uptake by hydroxide-catalyzed formaldehyde hydration. The measured mixing ratio is close to the  $0.18$  ppbv prediction of a tropospheric chemistry model calculation. The methane oxidation chain probably is the sole formaldehyde source in the Enewetak area. The total formaldehyde flux as carbon into the ocean is  $\sim 2\%$  of the estimated total organic carbon from rainout and washout. About 1-3% of the calculated column formaldehyde production is removed from the atmosphere by these processes.

Supported by: National Science Foundation Grant OCE 77-12914.

ORGANIC AND BIOLOGICAL CHEMISTRY

STUDIES OF ELEMENT INCORPORATION  
BY MARINE PHYTOPLANKTON  
WITH SPECIAL REFERENCE TO BARIUM

Donald C. Bankston, Nicholas S. Fisher,  
Robert R.L. Guillars and Vaughan T. Bowen

Small populations of various species of marine phytoplankton were batch-cultured in natural seawater media, under controlled conditions. Each culture was harvested by filtration during, or (in a few exceptional cases) after, the phase of exponential growth, dried, ashed, and then analyzed for barium, copper and silicon by a technique employing de plasma optical emission spectrometry.

Within the pooled sample of algal clones studied, and within each of three phylogenetic subsets of this sample, barium uptake was positively correlated with that of copper. The heaviest accumulators of barium and copper were the dinoflagellates. The diatoms and coccolithophores we studied were low accumulators of these elements. The uptake of barium and copper in several of the groups investigated was significantly lower in silicon-enriched, than in unenriched, media.

Certain algae having no known nutritive requirement for silicon, nevertheless accumulated it in sizeable amounts from silicon-enriched media. It is suggested that further research be done to determine whether this phenomenon ever occurs in the natural marine environment.

Published in: Department of Energy  
Environmental Quarterly.

Supported by: National Science Foundation Grant OCE 77-10876 and  
Department of Energy Contract  
EY-76-S-02-3563.

EFFECT OF NITROGEN SOURCE AND GROWTH RATE  
ON PHYTOPLANKTON-MEDIATED CHANGES  
IN ALKALINITY

Joel C. Goldman and Peter G. Brewer

Continuous cultures of the marine chrysophyte *Dunaliella tertiolecta* were grown on four different nitrogen sources:  $\text{NO}_3^-$ -N,  $\text{NO}_2^-$ -N,  $\text{NH}_4^+$ -N and urea-N. Influent N concentrations varied from 50 to 500  $\mu\text{g}$ -atoms liter $^{-1}$  and the specific growth rate ranged from 0.1 to 1.1 day $^{-1}$ . Alkalinity changes, measured by potentiometric titration, were consistent with a simple stoichiometric model in which  $\text{OH}^-$  production is

balanced by  $\text{NO}_3^-$  and  $\text{NO}_2^-$  uptake,  $\text{H}^+$  production is balanced by  $\text{NH}_4^+$  uptake and no change occurs when the uncharged species urea is assimilated. Neither the influent N concentration nor the growth rate had any effect on the 1:1 stoichiometry between N-uptake and alkalinity change. The titration data were corrected for a small, constant, acidic offset of 35  $\mu\text{e}/\text{kg}$  caused by ion-exchange reactions on the glass-fiber filters which had been pre-rinsed with distilled water prior to filtering the culture samples. The strong stoichiometry between alkalinity change and ionic N uptake precludes the possibility of excretion of an organic acid (e.g. glycolic acid) stronger than carbonic acid. However, excretion of a salt of an organic acid cannot be ruled out. In general, our results are consistent with the notion that excretion of glycolic acid by healthy marine phytoplankton cells is minimal.

Supported by: NOAA Office of Sea Grant,  
Grant 04-8-M01-149.

POLYCYCLIC AROMATIC HYDROCARBONS  
IN AN ANOXIC SEDIMENT CORE  
FROM THE PETTAQUAMSCUTT RIVER  
RHODE ISLAND, U.S.A.

Ronald A. Hites, Robert E. LaFlamme,  
John G. Windsor, Jr.,  
John W. Farrington and Werner G. Deuser

Fifteen sections from an anoxic sediment core were analyzed for polycyclic aromatic hydrocarbons (PAH). Two types of PAH were observed: (a) those from combustion sources such as pyrene and chrysene, and perylene. The combustion PAH levels in core sections dated between 1900 and 1970 were much higher than in earlier sections; this indicated an anthropogenic origin of these PAH at this location. The perylene and retene core profiles show significant anomalies during the period 1855-1875. Organic carbon does not fluctuate markedly but  $\delta^{13}\text{C}$  of organic carbon shows several unexplained excursions; one of which correlates with the perylene and retene anomalies.

Supported by: National Science Foundation Grant OCE 77-20252; Department of Energy Contract EE-77-5-02-4256; and Bureau of Land Management (via Interagency Agreement NOAA 550-IA-7-20).

PCBs IN CLAMS MERCENARIA MERCENARIA FROM  
THE NEW BEDFORD HARBOR, MASSACHUSETTS AREA

Walter I. Haten, Donald W. Allen  
Phillips D. Brady,  
Alan C. Davis and John W. Farrington

PCB concentrations in clams (*Mercenaria mercenaria*) and oysters (*Crassostrea virginica*) from 197 stations of the western and New Bedford Harbor areas of Buzzards Bay, Massachusetts clearly designate the New Bedford Harbor area as severely polluted with up to 5 ppm dry weight of PCBs in clams. The most likely sources of the PCB input are chronic releases from two electrical component manufacturers in New Bedford. A close proximity of the shellfish to the source of input is indicated by the high relative abundance of the di, tri and tetra-chlorobiphenyls. The data suggest that the New Bedford Harbor area should be considered along with the Hudson River and Chesapeake Bay as one of the major sources of PCB inputs to the northeastern U.S. coastal area.

Supported by: Environmental Protection Agency Contract R 8042-15.

TRANSFORMATION REACTIONS OF BIOGENIC  
ORGANIC COMPOUNDS AT THE SEDIMENT-WATER  
INTERFACE

Robert B. Gagosian

This is a discussion of the transformations undergone by certain organic compounds of biological origin. The reactivities and the mechanisms of degradation and formation of these compounds are explained using some examples taken from the category of compounds well-known as biological tracers. There are (1) oxidation, hydrogenation, and dehydration of steroid alcohols and (2) transformation of amino acids and (3) formation of humic substances in sea water by condensation of fatty acid, amino acids, sugar, amino sugar and other organic compounds.

Published in: Proceedings of Colloque International C.N.R.S. Biogéochimie de la Matière Organique à l'Interface Eau-Sédiment Marin.

Supported by: National Science Foundation Grants OCE 74-09991 and OCE 77-26084.

PROCESSES CONTROLLING THE STANOL/STENOL  
RATIO IN SEAWATER AND SEDIMENTS  
OF THE BLACK SEA

Robert B. Gagosian, Cindy Lee  
and Franz Heinzer

Steroidal alcohols, ketones and hydrocarbons have been used as tracers for the transformation processes of biogenic organic matter in Recent sediments. Several of these studies have been concerned with one of the sedimentary transformation reactions of steroidal alcohols, the reduction of stenols to stanols. However, little attention has been directed towards the role of the overlying water column in controlling sedimentary stenol/stanol distributions.

We discuss here the major processes controlling a specific transformation reaction (stenol to stanol conversion) of a class of biogenic organic compounds. These conclusions are based on results obtained by sampling both the sediments and the overlying water column from two stations in the Black Sea.

Published in: *Nature*, 280: 574-576.

Supported by: National Science Foundation Grants OCE 74-09991, OCE 75-15017, OCE 77-26084 and OCE 77-26189.

STEROID TRANSFORMATIONS IN RECENT  
MARINE SEDIMENTS

Robert B. Gagosian, Steven O. Smith  
Cindy Lee, John W. Farrington  
and Nelson M. Frew

The surface sediment and overlying water column from three Recent sedimentary environments, Walvis Bay off southeastern Africa, the Black Sea, and the western North Atlantic, have been analyzed for stenols and their transformation products, stanols, sterenes and steroid ketones. The steroid distributions in surface sediments are controlled by inputs from source organisms and from microbial or chemically mediated reactions occurring at the sediment water interface or in the overlying water column. A general correlation was found to exist for various steroidal compounds in sediments from each area suggesting related reaction sequences. Also, the steroid transformation products correlated with photoproduction in the overlying waters as well as with the oxic and anoxic conditions of the sedimentary environment studied.

Supported by: National Science Foundation Grants OCE 74-09991 and OCE 77-26084; ONR Contract N00014-66-00241; NR083-004.

STEROLS OF AGARUM CRIBOSUM: DESMOSTEROL IN  
A BROWN ALGA

Joan D. Newburger, J. John Uebel,  
Miyoshi Ikawa, Kenneth K. Andersen and  
Robert B. Gagosian

The sterol composition of the cold water brown alga *Agarum cribosum* was determined by GC-MS. Six of the seven sterols found were identified as stigmasta-5, (E)-24(28)-dien-3-ol (fucosterol), 24-methylenecholest-5-en-3-ol (24-methylenecholesterol), cholest-5-en-3-ol (cholesterol), 3-hydroxycholest-5-en-24-one (24-ketocholesterol), 24-stigmasta-5,28-diene-3,24-diol (saringosterol) and cholesta-5,24-dien-3-ol (desmosterol).

Published in: *Phytochemistry*, 1979,  
Vol. 18, pp. 2042-2043.

Supported by: National Science Foundation Grants OCE 74-09991 and OCE 77-26084.

GENERATION AND MIGRATION OF HYDROCARBONS  
IN OFFSHORE SOUTH TEXAS GULF COAST SEDIMENTS

Alain Y. Huc and John M. Hunt

The hydrocarbon content of two thick tertiary sequences from the Gulf Coast (South Padre Island and Mustang Island) was studied using a headspace technique, thermal distillation, pyrolysis and solvent extraction. The threshold of oil generation was determined to occur in the range of 3050 m (10,000 feet; 120°C) in Miocene sediments.

In the South Padre Island well, the distribution of the different classes of hydrocarbons along the sedimentary column suggests some updip migration processes are occurring.

Supported by: Department of Energy Contract EG-77-S-02-4392.

THE FUTURE POTENTIAL OF DEEP GAS

John M. Hunt

The potential for deep conventional gas accumulations world-wide may be much greater than has been assumed in the past. Considering that structural and trapping conditions can be just as favorable in this deep range as at shallower depths, the critical factors remaining are (1) an adequate source for the gas (2) sufficient porosity and permeability

for economic production, and (3) favorable conditions for preservation of the hydrocarbons since their accumulation.

Today drilling companies talk of building rigs capable of drilling to 15,000 m (about 50,000 ft). The deep Tuscaloosa gas discoveries in South Louisiana have sparked new interest in deep drilling and raised the question as to the potential of deep gas accumulations world-wide. This paper discusses the geochemical aspects of deep gas, namely, the sources of these hydrocarbons, the depth of peak gas generation, the factors causing a gas floor, and the prospects for finding large accumulations in the future. It concludes that deep conventional gas accumulations may well be our major fossil fuel world energy source when the oil begins to run out sometime in the next century.

Published in: Proceedings of UNITAR Conference, Montreal.

Supported by: Department of Energy Contract EG-77-S-02-4392.

THE ORGANIC MATTER OF A GULF COAST WELL STUDIED BY A THERMAL ANALYSIS - GAS CHROMATOGRAPHY TECHNIQUE

Alain Y. Huc, John M. Hunt  
and Jean K. Whelan

A thermal analysis - gas chromatography technique, previously described by Whelan, et al. (1979) has been used to analyze cuttings from a Continental Offshore Stratigraphic Test (COST #1) drilled in the Gulf Coast of the U.S.A. The data allowed an evaluation of the degree of maturation of the organic matter and provided an accurate determination of the depth of the threshold of intense oil generation at 10,000 feet. Qualitative changes of hydrocarbons in the C<sub>7</sub>-C<sub>14</sub> range were determined by gas chromatography and confirmed by gas chromatography-mass spectroscopy. These data are discussed in terms of generation and migration processes. The catagenetic evolution results in a strong tendency for a proportional increase in n-alkanes. Mass transfer phenomena may be responsible for updip movement of the lighter hydrocarbons.

Published in: Proceedings of the Geochemical Exploration Symposium, Hanover, Germany, April 1980.

Supported by: Department of Energy Contract EG-77-S-02-4392.

SOURCE ROCK CHARACTERIZATION BY THERMAL DISTILLATION AND PYROLYSIS

John M. Hunt

In studies on the origin and accumulation of petroleum, the thermal distillation - pyrolysis technique has the potential to define petroleum source rocks in terms of the quantity, type and maturation state of the organic matter, and to give a detailed hydrocarbon analysis in a manner suitable for correlation purposes. Examples are given of the use of this method in analyzing the Cretaceous LaLuna Shale of South America, and tertiary shales taken at various depths in a U.S. Gulf Coast well.

Published in: The Proceedings of the Karcher Symposium, Oklahoma City, OK.

Supported by: Department of Energy Contract EG-77-S-02-4392.

STEROLS IN DECOMPOSING SPARTINA ALTERNIFLORA AND THE USE OF ERGOSTEROL IN ESTIMATING THE CONTRIBUTION OF FUNGI TO DETRITAL NITROGEN

Cindy Lee, Robert W. Howarth  
and Brian L. Howes

Changes in concentrations of free sterols in decomposing *Spartina alterniflora* indicate that this marsh grass may be a significant source of sterols, primarily sitosterol, to tidal waters. These tidal waters may then transport the sterols (adsorbed to particulate matter) to nearby coastal sediments. One sterol found in *Spartina detritus*, ergosterol, is commonly found only in fungi and is not present in living grass. The concentration of ergosterol in the detritus was used to estimate fungal biomass. These results, and direct bacteria counts, show that the living cells of these microbes account for only a minor part of the relative increase in nitrogen observed during decomposition.

Published in: Limnology and Oceanography (in press).

Supported by: National Science Foundation Grants OCE 77-26084, DEB 76-83877 and DEB 78-03557.

GEOCHEMISTRY OF STEROLS IN SEDIMENTS  
FROM BLACK SEA AND THE SOUTHWEST AFRICAN  
SHELF AND SLOPE

Cindy Lee, Robert B. Gagosian  
and John W. Farrington

Surface sediment samples from the shelf and continental slope off southwest Africa and sediment cores from the deepest part of the Black Sea were analyzed for sterols. Because the organic matter in these anoxic sediments is relatively well-preserved, the input from source organisms in the water column is important in controlling sterol distribution patterns. The sterol distribution on the Namibian shelf is complex, probably because of the great spatial and temporal variability of biological productivity caused by seasonal upwelling and changes in oxygen concentration. The Black Sea, perhaps because of greater physical stability of the water column, has sterol distributions which can be explained by microbial activity or chemical processes acting on a constant input of organic carbon from surface production.

Published in: *Organic Geochemistry*  
(in press).

Supported by: Office of Naval Research Contract N0014-66-CO 24/NR 038-004 (J.W.F.); National Science Foundation Grants OCE 74-09991 (R.B.G.); OCE 75-15017 (H.W.J.); OCE 77-26084 (R.B.G.); and OCE 77-26180 (C.L.).

MICROBIAL PRODUCTION OF EXTRACELLULAR  
MATERIAL: IMPORTANCE OF BENTHIC ECOLOGY

John Hobbie and Cindy Lee

It has long been assumed that microbes make up most of the food of detritivores. While this is reasonable for small animals, such as protozoans and nematodes, there is some doubt that microbes are abundant enough in sediments to nourish a non-selective feeder. The hypothesis is presented here that the extracellular mucopolysaccharides of microbes are more abundant than the microbes themselves and provide the majority of the food for many benthic animals. The evidence for this comes from studies of the attachment of bacteria to particles, from measures of microbial biomass and nitrogen in sediments and litter, and from indications of the accumulation of microbial slimes in situations where water moves past surfaces (e.g., incubation chambers in the ocean, rocks in streams). The source of the mucopolysaccharide could be the dissolved organic matter of the water.

Published in: *Marine Benthic Dynamics*,  
K. Tenore and B. C. Coull (eds.)  
Univ. of South Carolina Press.

Supported by: National Science Foundation Grants OCE 77-26180, DEB 76-83877 and DPP 77-23879.

HYDROCARBONS IN CONTEMPORARY  
AQUATIC SEDIMENTS

Stuart G. Wakeham and John W. Farrington

Quantitative and qualitative distributions of alkanes, alkenes and aromatic hydrocarbons from a number of marine and freshwater sediments are discussed in terms of sources, chemical and biochemical reactions and biological and geochemical transport processes. Low hydrocarbon levels are present in deep sea, continental shelf and slope, and lake sediments remote from anthropogenic activities. Nevertheless, the cycloalkanes and aromatic hydrocarbons are consistent with an anthropogenic pyrolysis source, while several aromatic hydrocarbons apparently have early-diagenetic origins from biogenic precursors. Surface sediments near known sources of anthropogenically-generated organic material containing elevated hydrocarbon concentrations indicated chronic contamination. Depth distributions in sediment cores show that these sediments contain an historical record of anthropogenic inputs of hydrocarbons to the aquatic environment. Finally, marked differences in biologically-produced hydrocarbon arrays in surface sediments from the western Atlantic and the southwest African continental shelves may be explained in terms of differing hydrocarbon sources and depositional environments.

Published in: *ACS Symposium Volume*.

Supported by: NOAA Sea Grant Contract (NA79AA-D-00102). Department of Energy Contract EE-77-S-02-4256 and IA7-20.

DIAGENETIC POLYCYCLIC AROMATIC HYDROCARBONS  
IN RECENT SEDIMENTS: STRUCTURAL INFORMATION  
OBTAINED BY HIGH PRESSURE LIQUID  
CHROMATOGRAPHY

Stuart G. Wakeham, Christian Schattner  
and Walter Giger

Recent sediments from Greifensee, Switzerland and Lake Washington, northwest USA, were analyzed for polycyclic aromatic hydrocarbons (PAH) with the purpose of better understanding the diagenetic formation of aromatic hydrocarbons in the recent aquatic environment. High pressure liquid chroma-

tography proved to be a valuable analytical tool, in conjunction with glass-capillary gas chromatography and gas chromatography/mass spectrometry, in elucidating structures of the natural PAH. Greifensee contained only a pair of triaromatic-tetracyclic PAH, whereas Lake Washington contained a wide range of tetracyclic and pentacyclic compounds with two, three, and four aromatic rings. Explanations for this difference are discussed in terms of differing sources of precursor compounds and variations in depositional environments.

Published in: Ninth International Meeting of Organic Geochemistry, Newcastle-Upon-Tyne, September 17-20, 1979.

Supported by: ONR Contract N00014-74-CO262 NR083-004.

#### FECAL PELLETS AT DSDP SITE 436

Peter R. Thompson and Jean K. Whelan

Coarse fractions of samples from DSDP Site 436 contained abundant diatoms, radiolaria, volcanic debris, rare foraminifera, and numerous fecal pellets. The morphology of four types of ovoid and rodlike pellets is described according to simple shape criteria, but are not assigned taxonomic affinity. Organic geochemical analyses reveal significant differences in the aromatic compounds pyrolyzed from the organic matrix which serve as means to distinguish pellet types. Comparison of whole sediment analyses to values derived from picked concentrates of pellet types suggests that some hydrocarbon skeletons are concentrated in the pellets. We find no evidence that ocean plate sediments typical of those recovered from Site 436 have been incorporated into the landward wall of the Japan Trench as recovered from Site 434. This conclusion is based on the absence of fecal pellets in Site 434 sediments and on the organic matter differences between Sites 434 and 436.

Published in: Initial Reports of the Deep Sea Drilling Project.

Supported by: National Science Foundation Grant OCE 77-26999.

#### C<sub>1</sub>-C<sub>7</sub> VOLATILE ORGANIC COMPOUNDS IN SEDIMENTS FROM IPOD LEGS 56 AND 57 THE JAPAN TRENCH

Jean K. Whelan and John M. Hunt

Volatile C<sub>1</sub>-C<sub>7</sub> components in sediments were examined for Japan Trench Sites 438, 439, 435, 440, 434 and 436 proceeding from

West to East. Levels of all components are lowest in the highly fractured sediments of Sites 440 and 434. A number of alkenes, furans and sulfur compounds were detected in higher levels than have been noted in any other DSDP sediments examined to date. The types, amounts, and specificity of occurrence were similar to those from one-meter gravity cores we have examined which bear a significant biological imprint. Site 436 shows high levels of saturated and aromatic hydrocarbons as well as olefins, including traces of dimethylcyclopentenes and the highest level of cyclohexene detected in any DSDP sediment we have examined to date. The results from Site 436 were unexpected considering the low organic carbon content, absence of biogenic methane, and evidence of an oxic depositional environment at this site.

Supported by: National Science Foundation Grant OCE 77-26999.

#### APPLICATIONS OF THERMAL DISTILLATION-PYROLYSIS TO PETROLEUM SOURCE ROCK STUDIES AND MARINE POLLUTION

Jean K. Whelan, John M. Hunt and Alain Y. Huc

The technique involves heating a 0.5 - 50 mg sample of wet sediment from 100 to 800°C at 20°/min and measuring evolved hydrocarbons as a function of temperature. Unaltered absorbed hydrocarbons evolve at 100 to 150°C, and cracked or pyrolyzed hydrocarbons at 650 to 800°C in two well separated peaks, P<sub>1</sub> and P<sub>2</sub>. The compounds in P<sub>1</sub> and P<sub>2</sub> are analyzed by capillary gas chromatography (GC) and GC mass spectrometry. An increasing ratio of P<sub>1</sub>/(P<sub>1</sub>+P<sub>2</sub>) indicates increasing petroleum source rock maturity. Data are presented for known source rocks and a test well (COST I, Gulf of Mexico, USA). Applications of method to examination of oil and chemical pollutants in organisms and surface sediments are given. Results to date have shown that increasing degree of pollution causes an increasing P<sub>1</sub>/P<sub>2</sub> ratio and increasing complexity of the P<sub>1</sub> peak. The hydrocarbon composition of P<sub>2</sub> has been used to fingerprint and trace high molecular weight organic-rich particles in the marine environment.

Published in: Journal of Analytical and Applied Pyrolysis.

Supported by: NOAA Office of Sea Grant 048M01149, Department of Energy Contract EG-77-S-02-4392.

C<sub>1</sub>-C<sub>5</sub> HYDROCARBONS  
FROM CORE GAS POCKETS - IPOD LEGS 56 & 57

Jean K. Whelan and Shunji Sato

C<sub>1</sub>-C<sub>5</sub> hydrocarbons from Legs 56 and 57 sediment gas pockets were analyzed on ship-board. Results suggest that the C<sub>2</sub>-C<sub>5</sub> hydrocarbons accompanied biogenic methane and were generated at low temperatures - less than 50°C - either by microorganisms or by low temperature chemical reactions. Neopentane, a rare constituent of petroleum, was the major C<sub>5</sub> component (about 80%) throughout much of Site 438. This compound which appeared in smaller amounts at sites 434, 439, 440 and 441 seemed to correlate with either fractured or coarse-grained sediments. Scatter in C<sub>4</sub> and C<sub>5</sub> isomer ratios and generally good correlation between C<sub>3</sub>, C<sub>4</sub> and C<sub>5</sub> components suggest local sources for these molecules.

Supported by: National Science Foundation Grant OCE 77-26999.

VOLATILE ORGANIC COMPOUNDS IN SEAWATER  
FROM THE PERU UPWELLING REGION

Philip M. Gschwend, Oliver C. Zatiriou  
and Robert B. Gagosian

The concentrations and distributions of specific volatile organic compounds in seawater were determined at six stations in the upwelling region off the coast of Peru using vapor phase stripping, glass capillary gas chromatography, and gas chromatography-mass spectrometry techniques. Saturated and unsaturated hydrocarbons, alkylated benzenes, and aldehydes were found. Individual compound concentrations varied from < 2 ng kg<sup>-1</sup> to about 60 ng kg<sup>-1</sup>. All of the volatile compounds occurred at higher concentrations in surface waters than in deeper waters, but each compound class demonstrated a unique horizontal distribution. Possible sources and transformations are discussed based on spatial distributions and correlations with hydrographic data.

Supported by: National Science Foundation Grants OCE 74-22781 and OCE 77-26084; Department of Commerce, NOAA, Office of Sea Grant, 04-7-158-44104.

G E O C H E M I S T R Y

THE SOLUBILITY OF CaCO<sub>3</sub> IN SEAWATER  
AT 2°C BASED UPON IN SITU SAMPLED  
PORE WATER COMPOSITION

Frederick L. Sayles

Analyses of the concentration product Ca<sup>2+</sup> × (CO<sub>3</sub><sup>2-</sup>) in the pore waters of marine sediments have been used to estimate the apparent solubility products of sedimentary calcite (K<sub>SPc</sub><sup>1</sup>) and aragonite (K<sub>SPa</sub><sup>1</sup>) in seawater. Regression of the data gives the relation

$$\ln K_{SPc}^1 = 1.94 \times 10^{-3} P - 14.59.$$

The 2°C, 1 atm value of K<sub>SPc</sub><sup>1</sup> is, then, 4.61 × 10<sup>-7</sup> mol<sup>2</sup> l<sup>-2</sup>. The pressure coefficient yields a ΔV<sub>r</sub><sup>1</sup> at 2°C of -43.8 cc/atm. A single station where aragonite is present in the sediments gives K<sub>SPa</sub><sup>1</sup> = 9.2 × 10<sup>-7</sup> (5°C,

81 atm). The calcite data are very similar to those determined experimentally by Ingle et al. (1973) for K<sub>SPc</sub><sup>1</sup> at 2° and 1 atm. The calculated ΔV<sub>r</sub><sup>1</sup> is also indistinguishable from the experimental results of Ingle (1975) if ΔV<sub>r</sub><sup>1</sup> is assumed independent of pressure.

Supported by: National Science Foundation Grants OCE 76-81620 and 78-24685.

PHOSPHORUS IN SUSPENDED SEDIMENTS  
OF THE AMAZON RIVER

Elsa M. Chase and Frederick L. Sayles

Substantial quantities of soluble phosphorus are released from natural suspended sediments from the Amazon River, over periods of many days, when such sediments are kept in suspension in seawater or in 0.01 M NTA (nitrilotriacetic acid, a chelator). These results are interpreted, with the help of other chemical analyses, in terms of various physico-chemical forms in which the P may exist in sediments. Potential availability of this P to estuarine algae is discussed. Flux calculations indicate that available particulate P may be as much as 15 times greater than dissolved PO<sub>4</sub>-P during the Amazon rainy season.

Supported by: National Science Foundation Grants OCE 78-10277 and OCE 77-08631.

GEOCHEMICAL VARIATION AND PETROGENESIS  
OF BASALT GLASSES  
FROM THE CAYMAN TROUGH SPREADING CENTER

Geoffrey Thompson, Wilfred B. Bryan  
and William G. Melson

Compared to typical mid-ocean ridge basalts (MORB), basalt glasses erupted from the transverse spreading center within the Cayman Trough have higher contents of  $TiO_2$ ,  $SiO_2$ ,  $K_2O$ ,  $P_2O_5$ , Zr, Y, Sr and Ba. The Cayman glasses have some unique compositional features and seem transitional between MORB and compatible element enriched basalts from certain oceanic regions such as the mid-Atlantic Ridge near  $43^{\circ}N$ , the triple junction near Bouvet and fracture Zone B at the FAMOUS (MAR  $36^{\circ}N$ ) spreading center. The range in composition represented by the Cayman glasses suggests a fractionated magma series. The major elements define an apparent cotectic in the normative plagioclase-pyroxene-olivine ternary, which is systematically offset in the plagioclase field compared to other MORB trends. Model fits invoking fractional crystallization are very good for both major and trace elements, with no apparent 'decoupling' of the compatible elements as observed in the FAMOUS ( $36^{\circ}N$ ) spreading center. Calculations indicate that, like MORB, three phase crystallization is required to explain the major and trace element variations, although only plagioclase and olivine are observed as liquidus (phenocryst) phases. A possible model involving high-pressure crystallization of pyroxene is suggested by analogy with experimental data and may be related to the special tectonic setting of the Cayman Trough.

Published in: Journal of Geology.

Supported by: National Science Foundation Grant OCE 77-18533.

SOMALI BASIN AND ARABIAN SEA, NORTHWEST  
INDIAN OCEAN: EVIDENCE FOR HETEROGENEOUS  
PRIMARY MORBS AND MANTLE SOURCES

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

Basalts from 5 Deep Sea Drilling Project (DSDP) sites in the northwest Indian Ocean (Somali Basin and Arabian Sea) have general geochemical features consistent with a spreading origin at the ancient Carlsberg Ridge. However, compared to most MORBs from other oceans they have low  $TiO_2$  and Zr contents; there is no evidence that the mantle source of these northwest Indian Ocean basalts was enriched in incompatible

elements relative to the Atlantic and Pacific ocean mantles. In detail, incompatible element abundance features in these DSDP basalts establish that they evolved from several compositionally distinct parental magmas. In particular, basalts from site 236 in the Somali Basin have relatively high  $SiO_2$  and low Na, P, Ti, and Zr contents. These compositional features along with low normative olivine contents are similar to those proposed for melts derived by two-stage (or dynamic) melting.

Published in: Contributions to Mineralogy and Petrology.

Supported by: National Science Foundation Grant OCE 76-15858.

ANALYSIS OF GEOLOGIC MATERIALS USING AN  
X-RAY FLUORESCENCE SYSTEM

Brian Schroeder, Geoffrey Thompson,  
Margaret Sulanowski and John N. Ludden

The analytical techniques we use for x-ray fluorescence analyses of major and trace elements in oceanic rocks give good precision and accuracy and are applicable to a wide range of geologic materials. The use of an automated, software-controlled spectrometer (Phillips AXS System) markedly increases the rapidity of analysis and frees the operator for the sample preparation required. The speed and automation of analysis apparently does not compromise the precision and accuracy.

The major elements absorption coefficients calculated from the Rasberry-Heinrichs equation are empirically determined on reference rocks, stored on diskettes, and used to correct background-corrected intensity ratios of unknowns before determining actual concentrations on-line. Precision and accuracy, with the exception of Na, are generally in the 0.5 to 3% range. For the trace elements, intensities (corrected for background and peak overlap) are corrected for mass absorption off-line before being used to determine concentrations. As with the major elements, the use of reference rocks for calibration leads to good precision and accuracy, making the technique applicable to a wide range of materials. Precision and accuracy appear to be generally in the 1 to 5% range.

Published in: X-Ray Spectrometry.

Supported by: National Science Foundation Grants 22971, 26842, 09019, 09015; Department of Energy Contract EY-76-S-02-3563; and the Ocean Industry Program of the Woods Hole Oceanographic Institution.

# GEOLOGY and GEOPHYSICS

GG-1

DEPARTMENT OF GEOLOGY AND GEOPHYSICS

*John I. Ewing, Department Chairman*

## G E O L O G Y

COMPARATIVE MORPHOLOGY OF  
ANCIENT AND MODERN PILLOW LAVAGary Wells, Wilfred B. Bryan  
and Thomas H. Pierce

Pillow lava is a common feature of volcanic stratigraphy throughout geologic time. A comparison is made between the morphology of oceanic pillows from the FAMOUS area of the Mid-Atlantic Ridge, recent pillows from Iceland and Archean pillows from the Rouyn-Noranda area of northwestern Quebec. In two dimensions the shapes and sizes of pillows from the three areas are similar but not identical. Abyssal and subglacial lava flows, when viewed in three dimensions, appear to be tubular lava forms similar to subaerial pahoehoe flows. Archean pillows also appear to be interconnected. Evidence of this includes broken selvages, lenticular quartz-filled cavities representing fossil lava levels, and the "pinch and swell" nature of elongate pillows. The stratigraphy of Archean volcanics and modern-day oceanic crust as seen in DSDP holes is similar. Both consist of interlayered massive, pillowed and breccia units in an apparent random order. However, there appears to be a preponderance of pillowed flows in the modern volcanics compared to the ancient examples. Archean flows appear to be longer, and possibly, thicker than those at present day ocean ridges and individual Archean pillows are flattened and welded in places. These observations suggest that the rate of eruption in the Archean may have been greater than in known areas of the Mid-Atlantic Ridge. Pillow morphology and vesicle size and distribution in the Archean examples are consistent with a relatively shallow depth of eruption for the Archean sequences. Overall, the styles of eruption of both the Archean and modern pillow sequences appear to have been similar.

Published in: Jour. Geol. 87, 427-440.

Supported by: NASA Basaltic Volcanism  
Project (Bryan funded through  
L.P.I.) and NSF Grant OCE-77-26842.GEOLOGICAL AND GEOPHYSICAL INVESTIGATION  
OF THE MID-CAYMAN RISE SPREADING CENTER:  
GEOCHEMICAL VARIATION AND PETROGENESIS  
OF BASALT GLASSESWilfred B. Bryan, Geoffrey Thompson  
and William G. Melson

Compared to typical mid-ocean ridge basalts (MORB), basalt glasses erupted from the transverse spreading center within the Cayman Trough have higher contents of  $TiO_2$ ,  $Na_2O$ ,  $K_2O$ ,  $P_2O_5$ , Zr, Y, Sr and Ba. The Cayman glasses have some unique compositional features and seem transitional between typical MORB and incompatible-element enriched basalts from certain oceanic regions such as the mid-Atlantic Ridge near  $43^{\circ}N$ , the triple junction near Bouvet, and Fracture Zone B at the FAMOUS (MAR  $37^{\circ}N$ ) spreading center. The compositional variation represented by the Cayman glasses suggests a fractionated magma series. The major elements define an apparent cotectic in the normative plagioclase-pyroxene-olivine triangle, which is systematically offset into the plagioclase field compared to most other MORB trends. Model fits invoking fractional crystallization are very good for both major and trace elements, with no apparent 'decoupling' of the incompatible elements as observed in the FAMOUS ( $37^{\circ}N$ ) spreading center. Calculations indicate that, like typical MORB, three phase crystallization is required to explain the major and trace element variations, although only plagioclase and olivine are observed as liquidus (phenocryst) phases. High-pressure crystallization of pyroxene is suggested by gabbro mineral assemblages and by analogy with experimental data and may be favored by the special tectonic setting of the Cayman Trough. Other geochemical peculiarities of the data set may be related in part to characteristics of the mantle source beneath the equatorial Atlantic and/or Caribbean plate.

In press: Jour. Geology.

Supported by: NSF grants OCE 77-01122  
and OCE 75-18533.

AN EVALUATION OF FRACTIONAL  
CRYSTALLIZATION AND THE ORIGIN  
OF LAVAS FROM THE 90°E RIDGE,  
EASTERN INDIAN OCEAN

John N. Ludden, Geoffrey Thompson,  
Wilfred B. Bryan and Frederick A. Frey

Ferrobasalts from DSDP Sites 214 and 216 on the 90°E ridge are characterized by: high absolute iron (FeO 12.9 wt. %); FeO/MgO 1.9; TiO<sub>2</sub> 2.0 wt. %. Their trace element abundances indicate a tholeiitic affinity; however, they are distinct from mid-ocean ridge incompatible element-depleted tholeiites due to higher contents of Ba, Zr and Sr, and flat to slightly light-REE enriched chondritenormalized REE patterns. Calculations using major and trace element abundances and phase compositions are generally consistent with a model relating most major elements and phase compositions in Site 214 and 216 ferrobasalts by fractionation of clinopyroxene and plagioclase. However, some incompatible element (IE) abundances for Site 216 basalts are not consistent with the fractional crystallization models. Basalts from Site 214 can be related to andesitic rocks from the same site by fractionating clinopyroxene, plagioclase and titanomagnetite.

Site 254 basalts, at the southern end of the 90°E ridge, and island tholeiites in the Southern Indian Ocean (Amsterdam-St. Paul or Kerguelen-Heard) possibly represent the most recent activity associated with a hot-spot forming the 90°E ridge. These incompatible element enriched tholeiites have major element compositions consistent with those expected for a parental liquid for the Site 214 and 216 ferrobasalts. However, differences in the trace element contents of the basalts from the 90°E ridge sites are not consistent with simple fractional crystallization derivation but require either a complex melting model or a heterogeneous mantle source.

In Press: J. Geophys. Res.

NSF Grant 77-26647

THE SOUTH AUSTRALIAN CONTINENTAL MARGIN  
AND THE AUSTRALIAN ANTARCTIC SECTOR  
OF THE SOUTHERN OCEAN

John N. Ludden and Bruce H. Gillin

The Australian Antarctic sector of the Southern Ocean has been formed by asymmetric sea-floor spreading along an

east-west trending ridge. This ridge (the Southeast Indian Ridge) separates two major deepwater basins, the South Australian and South Indian Basins. Vigorous bottomwater circulation and regional productivity patterns have been important variables influencing sedimentation throughout the region.

The continental margin of southern Australia is a typical trailing-edge margin and is relatively underformed. The southern margin contains a well-defined continental shelf, slope and rise as well as several pronounced marginal plateaus and sedimentary basins. The continental margins of southern Australia and Antarctica have similar features despite the climatic and glaciological differences of the two land masses.

This paper will summarize the structural and morphological characteristics of the South Australian margin, South Australian Basin, Southeast Indian Ridge and South Indian Basin in the region between approximately 100°E to 150°E longitude. Sedimentation and depositional processes in the area will be discussed, and the evolution of the Australian-Antarctic sector of the Southern Ocean will be reviewed. The margins along western Tasmania, the Naturaliste Plateau and Antarctica are not included.

Economic interest in the mineral resource potential (in particular petroleum) of the Australian continental margin and scientific interest in the margin as a stable trailing-edge margin have produced an adequate seismic and coring data base with which to study the formative processes active on the southern margin. Exploration drill holes through Cretaceous/Tertiary sections across southern Australia have also been useful. Extensive geophysical, oceanographic and coring studies have been carried out in the Australian-Antarctic sector of the Southern Ocean by investigators using the research vessels Robert Conrad and Vema of Lamont-Doherty Geological Observatory, the Diamantina of Australia and the USNS Eltanin as part of the United States Antarctic Research Program. In addition, eight Deep Sea Drilling Project (DSDP) sites drilled with the Glomar Challenger between 104° and 150° longitude have provided sediment sequences useful in understanding the climatic evolution and paleoceanographic history of the Southern Ocean.

Supported By: NSF Grant DPP-78-21100

STATISTICAL SEDIMENTATION AND MAGNETIC  
POLARITY STRATIGRAPHY

Charles R. Denham

The completeness of the stratigraphic record can be estimated by comparing the number of recorded geomagnetic polarity intervals with the number expected for the particular age span. A magnetic polarity stratigraphy can be modeled usefully by Poisson two-state sedimentation. If hiatuses are infrequent or of short duration, then most of the expected polarity intervals will be recorded, but most of the observed polarity boundaries may mark gaps, rather than times of actual field reversal.

In Press: In Catastrophes and Earth's History, (Eds., W. A. Berggren, John van Couvering, Princeton Press).

Supported by: NSF Grant EAR 76-13359.

CONTINENTAL MARGINS--THEIR CLASSIFICATION  
AND PETROLEUM PROSPECTS

Kenneth O. Emery

Continental margins can be classified according to their stages of development as judged from published continuous seismic reflection profiles. Mapping of the stages of initial, youth, maturity, and old age shows that their distributions are related to plate movements and to sediment supply. The main information gaps are in the Arctic Sea, off Antarctica, in the open Indian Ocean, and along parts of eastern Asia. Even in these regions the stages of development can be inferred from related regions having available profiles and from general knowledge of the topography and structure. The distribution for the entire Earth is about 6% initial, 48% youth, 25% maturity, and 21% old age. Best petroleum prospects are believed to be mature margins and thick basin fills within youthful margins.

In Press: Bull. AAPG.

Supported by: Ocean Industries Program, WHOI.

GROWTH OF AN OCEANOGRAPHIC INSTITUTION

Richard L. Haedrich and Kenneth O. Emery

Oceanography as a profession is a very recent phenomenon, and most of its growth has occurred within the lifetimes of its present practitioners. We view its growth as a microcosm of the growth of science in

general. Taking the Woods Hole Oceanographic Institution as an example, formal organization in 1930 was followed by a period of virtually no growth until World War II. Practical concerns of national interest produced a spurt in growth, but following the war there was a nearly equal reversal toward normalcy. With the establishment of the Office of Naval Research in 1946 and the National Science Foundation in 1950, the field grew exponentially. Part of the expansion included the development of large administrations, formal educational programs, oceanographic curricula, graduate students, and expensive interdisciplinary and multi-investigator programs. At the same time, oceanographic investigations came to be conducted at many universities, colleges, and laboratories, rather than being monopolized by only a few large institutions. Funding leveled off in 1971, and then came the problems of coping with a steady state. As reflected in patterns of population structure, hiring and promotions, and leadership within the departments, there are different responses to this change. While personalities may figure somewhat the differences may be a function of differing stages of development of departments. For example, patterns in Biology, an old and established department, are different from those in Chemistry, a younger one.

Supported by: Bigelow Chair.

EROSION OF ROCK SHORES  
AT LA JOLLA, CALIFORNIA

Kenneth O. Emery and Gerald G. Kuhn

Detailed photographs and other measurements at La Jolla, California, repeated in 1979 after several decades provide information about processes and rates of rock shore and sea cliff erosion. Weathering and abrasion cause direct surface retreat particularly on steep slopes, but they are very slow on near-horizontal benches. Mass movements are episodic, and their resulting talus is comminuted by surface abrasion through sand-laden waves and currents. Measured rates of the various processes of marine erosion span a wide range by constitute a reasonable hierarchy for different exposures, processes, and lithologies.

Supported by: Ocean Industries Program, WHOI.

PRESENT STATUS OF OIL AND GAS  
FROM THE OCEAN FLOOR

Kenneth O. Emery

About 19% of the world's oil came from the continental shelves in 1978, a percentage that is slowly increasing; a smaller percentage of the gas is from offshore owing to handling problems. In deeper water beyond the shelf the best prospective provinces appear to be the inner marginal basins, the lower parts of mature continental slopes, and the inner continental rises. All three provinces probably contain petroleum source beds, reservoir beds, impervious caps, stratigraphic and structural traps, and temperatures at depth sufficient for maturation of their marine organic matter. These inferences are based upon geophysical studies and shallow drillhole samples, but to date not a single deep exploratory hole in them has been drilled and published. Although prospects for the presence of deep-ocean petroleum are believed to be good, its presence in exploitable quantities is not proven nor is the energy cost of its production known.

Supported by: Bigelow Chair.

SEDIMENTARY PROCESSES ON THE CONTINENTAL  
SLOPE OF NEW ENGLAND

Joseph C. MacIlvaine and David A. Ross

This paper presents the results of a series of detailed, small-scale geological studies on the continental slope off the northeastern United States. These studies show that slumping and turbidity currents are active and effective erosional agents in the area. Massive large-scale failure has occurred where the slope steepens from a gradient of  $1.4^{\circ}$  to  $7.6^{\circ}$ , producing scarps hundreds of meters in relief. Smaller scale slumps have occurred on other parts of the continental slope. Some of the material removed by slumping is emplaced at the foot of the continental slope as relatively intact blocks of 1 to more than 100 meters in thickness. Turbidity currents apparently initiated by slumping have eroded V-shaped gullies on the lower portions of the slope.

Bottom current activity is most influential at the shelf break, where it has sorted bottom sediments and resuspended fine material. Laboratory flume experiments and direct observations of the bottom, (using ALVIN and ALCOA SEAPROBE) indicate that the sediments on much of the continental slope generally are not norm-

ally affected by bottom currents. Biological activity, however, can cause both roughening and smoothing of the sediment surface, and the irregularities made by organisms will be reworked by currents. Biological production of fibrous structures can, on the other hand, make the sediment surface more resistant to erosion by bottom currents.

Published in: Jour. of Sed. Pet., Vol. 49, No. 2, p. 0563-0574.

THE RED SEA: A NEW OCEAN

David A. Ross

The Red Sea heavy-metal deposit may be the first one to be mined from the deep sea -- even before the much heralded manganese nodules. One should emphasize, however, that few if any legal problems affect the Red Sea heavy-metal deposits because they lie in a narrow sea surrounded by land, ownership belonging to Sudan and Saudi Arabia. This fact is a direct result of the early age of the Red Sea in its sea-floor spreading evolution.

Published in: Oceanus, Vol 22, pp. 34-39.

GEOLOGIC SIGNIFICANCE OF SEISMIC REFLECTORS  
IN THE DEEP WESTERN NORTH ATLANTIC BASIN

Brian E. Tucholke

Several major seismic horizons in the deep western North Atlantic have been calibrated according to age and physical and lithologic character by JOIDES drilling. Three horizons are discussed that are representative of the spectrum of stratigraphic relations in the basin. Horizon F, which ranges from Hauterivian to Barremian age, correlates with a sharp upward transition from limestones to black clays coincident with a rise in the calcite compensation depth. Widespread deposition of sediments enriched in biogenic silica occurred during the Eocene, and subsequent diagenesis formed chert beds; the upper lower to lower middle Eocene surface of these cherts matches Horizon A<sup>c</sup>, which is one of the strongest and most widespread reflectors in the basin. Both Horizon B and Horizon A<sup>c</sup> occur within continuously deposited sedimentary sections. Beneath the continental rise, Horizon A<sup>u</sup> correlates with a major unconformity eroded between late Eocene and early Miocene time by

southward-flowing abyssal currents. The reflector may have limited chronostratigraphic significance because of lateral migration of the abyssal current system with time. Several simple models are used to assess potential age significance of the seismic and lithologic boundaries and are compared to borehole data.

Supported by: NSF Grant OCE 76-02058 and  
ONR Contract N00014-79-C-0071 NR 083-004.

MESOZOIC LITHOFACIES DEVELOPMENT  
AND ECONOMIC POTENTIAL OF THE  
GEORGES BANK BASIN

James A. Austin and Elazar Uchupi

A lithologic interpretation of velocities from multichannel seismic reflection and refraction profiles from Georges Bank supports the presence of a Jurassic-Early Cretaceous reef trend underlying the outer continental shelf-upper continental slope. Strata north of the reef consist of Jurassic carbonates and Late Jurassic-Cenozoic clastics. Progradation of the clastics resulted in the extinction of the reef in earliest Late Cretaceous. The oil and gas potential of the Georges Bank basin is probably highest along both flanks of buried Mesozoic carbonate build-up. Other possible drilling targets are the flanks of the Yarmouth arch, a northwest trending basement high extending from Northeast channel to the continental slope.

Supported by: NSF/IDOE Grant I0074-04094;  
NSF Grant OCE 77-09421, NOAA Sea Grant  
04-7-158-44104 and 04-8-M01-749; and  
the State Department 1722-620214.

MESOZOIC-CENOZOIC REGRESSIONS  
AND THE DEVELOPMENT OF THE MARGIN  
OFF NORTHEASTERN NORTH AMERICA

Elazar Uchupi, Jeffrey P. Ellis,  
James A. Austin, Jr., George H. Keller  
and Robert D. Ballard

The development of the passive margin off northeastern North America was influenced by three major pre-Quaternary regressions. The first occurred in mid-Jurassic as a result of a ridge jump towards the continental margin. The second took place from latest Jurassic to earliest Late Cretaceous in response to the opening of the Bay of Biscay and the separation of North America and Eurasia. During this second regression, large segments of the shelf

were uplifted and eroded, and terrigenous wedges prograded over and buried outer shelf Mesozoic reef/bank carbonate complexes. The first submarine canyons were cut by turbidity currents on the continental slope at this time. The second regression accompanied a world-wide cooling which began in the late Eocene. Once again, the shelf underwent erosion and canyons were carved or exhumed by turbidity flows on the outer shelf and continental slope. These canyons served as conduits for the transport of large quantities of sediment to the continental rise. Despite the fact that eustatic sea-level changes caused by continental glaciation during the Plio-Pleistocene have modified and occasionally completely obliterated the effects of these earlier regressions, their significance for the evolution of the margin off northeastern North America is apparent.

Supported by: NOAA Sea Grant 04-7-158-44104;  
NSF Grants OCE 76-82146 and OCE 77-9421;  
and NSF/IDOE Grant 74-04094.

GEOLOGY OF THE NEW ENGLAND PASSIVE MARGIN

James A. Austin, Elazar Uchupi,  
Daniel R. Shaughnessy and Robert D. Ballard

Results of a detailed geophysical investigation have been used in conjunction with other available information to reconstruct the geologic history of the New England passive margin. Rifting between northeastern North America and Morocco began during the Middle Triassic, producing a complex series of horsts and grabens in the Precambrian/Paleozoic terrain. These grabens were filled with continental clastics, volcanics, and evaporites. When the North American and African continents separated and sea-floor spreading began 195-190 m.y.b.p., the continental edges were lifted and the rifts were truncated. This "break-up unconformity" is approximately the same age as the oldest oceanic crust emplaced by the spreading process. Continental separation took place along a basement "hinge zone" separating normal continental crust from continental crust radically altered by fracturing and intrusion of oceanic material.

As the continents drifted apart, the continental edges cooled and subsided. Atop this subsiding platform, strata of the "drift" sequence underlying the New England margin were deposited. Beneath Georges Bank, the lower part of this sequence is an

evaporite/carbonate unit of Early Jurassic age, and the upper part is a clastic wedge of Middle Jurassic-Cenozoic age. Total sediment thickness of both the "rift" and "drift" sequences in this region may be as much as 13 km, of which more than 80% is of Jurassic age. Beneath the seaward edge of Georges Bank and the upper continental slope is a Mesozoic reef/carbonate platform complex. This complex was an effective sediment barrier until it was buried by prograding clastics in the early Late Cretaceous. The foundation of the carbonate build-up is either altered continental or oceanic crust. The geographic position and relative steepness ( $5-8^{\circ}$ ) of the continental slope south of Georges Bank is due to this carbonate complex and its basement foundation.

Emplacement of the "drift" sequence was not continuous, but was disrupted by regressions during the Middle Jurassic, late Early Cretaceous, latest Cretaceous, latest Eocene-Oligocene, latest Miocene (Messinian), and Plio-Pleistocene. The Middle Jurassic regression may have been the result of a westward jump of the Mid-Atlantic Ridge, while the late Early Cretaceous regression was a response to the opening of the Bay of Biscay and the separation of Eurasia and North America. All of the more recent regressions were due to the onset of continental glaciation.

Supported by: NSF/IDOE Grant 74-04094; State Department 1722-620214; NSF Grant OCE 77-09421; and NOAA Sea Grant 04-7-158-44104 and 04-8-M01-149.

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

### ARC-CONTINENT COLLISION IN THE BANDA SEA REGION

Carl Bowin, G. Michael Purdy, Chris Johnston, George Shor, Lawrence Lawver, HMS Hartono and Peter Jezek

A 2-month marine geophysical study of the Banda arc region was conducted in late 1976 utilizing the ATLANTIS II of WHOI and the THOMAS WASHINGTON of SIO. Nineteen seismic refraction lines were successfully completed. Oceanic crust underlies the Banda Sea and Weber deep. Thick continental crust, 35-40 km, underlies the Australian shelf. Continental crustal thickness also occurs beneath the Timor and Aru troughs.

Low amplitude magnetic anomalies occur over the Australian shelf and extend to near the western edge of the Banda outer arc, and together with the occurrence of metamorphic rocks, suggest that continental crust may extend to the eastern lip of the Weber deep. Continuous seismic reflection profiling shows the Australian shelf sedimentary sequence to dip beneath the accretionary prisms of the outer Banda arc at the Timor and Seram troughs: the tectonic front of the subduction zone lies along the axis of these troughs. The bathymetric profile on the outer flank of the Timor and Seram troughs is unusual in that the profile asymptotically approaches a shallow depth near sea level and no outer rise is present as at oceanic trenches. An elastic flexure analysis of this topographic profile indicates that an elastic plate is an incorrect model for the lithosphere at this plate convergence zone. The Aru trough, although structurally on trend with the Timor trough, is not a site of subduction and compression tectonics. Instead, it is a place of crustal extension, and is an example of graben formation that is separating a block of Australian continental crust (beneath the Kai islands) from the Australian platform. The present lack of structural continuity between the Seram trough and the Aru and Timor troughs is best demonstrated by the pattern of gravity anomalies. The discontinuity between the Seram and Aru troughs supports the seismicity evidence that the Seram subduction zone is separate from the Southern Banda subduction zone that is continuous with that beneath Java to the west. The Bouguer gravity anomaly pattern indicates a division of the Banda arc into four segments: a southern segment, Timor to Babar, with relative plate convergence possibly trending about  $N 20^{\circ}W$  between the Banda and Australian plates; a central segment from Tanimbar to about Kasiui beneath which the Java to Timor Benioff zone is bent to a northward trend; a Seram segment that is converging with the Australian platform along approximately a  $S 70^{\circ}W$  direction; and a Buru segment that has rifted away from the Sula islands. The southern segment has been undergoing compressional deformation distributed across the width of the arc for the last 3 m.y. with attendant slowing of the differential slip rate between the leading edge of the accretionary wedge and the underthrust Australian margin crust. Oblique convergence and the bend of the Benioff zone produce in the

Tanimbar to Kasiui segment a slower convergence rate normal to the arc at the southern end which diminishes northward and changes to extension normal to the arc at the Aru trough. Thrust focal mechanisms indicate that subduction is presently active at the Seram trough. Sea floor spreading magnetic anomalies appear to have been found in the south Banda basin. They trend approximately N 60° to 70°E, similar to Cretaceous anomalies in the eastern Wharton basin, suggesting the possibility that the Banda Sea may be trapped oceanic crust. Five kilometer water depths and low heat flow (generally 1.5 HFU or less) are compatible with an old age (greater than 25 to 60 m.y.) for the Banda Sea crust.

We conclude that the Outer Banda arc from Buru around to Timor, and possibly to Sumba, contained Australian continental crustal blocks and fragments prior to its collision with the Australian margin in the last 3 to 6 million years. Continuous convergence following the arrival of a thick Australian margin sedimentary sequence to the south Banda subduction zone has led to deformation becoming distributed over the width of the arc and not simply being taken up on a single thrust surface. This scenario helps reconcile the geological relations observed on Timor, Seram, and Buru with the structural continuity of the Timor trough with the Java trench.

In Press: Bull. A.A.P.G.

Supported by: ONR Contract N00014-74-C-262, NR 083-004 and NSF/IDOE Grant OCE 78-19387.

THE GRAVITY FIELD OF THE  
U.S. ATLANTIC CONTINENTAL MARGIN

John A. Grow, Carl O. Bowin  
and Deborah R. Hutchinson

Approximately 39,000 km of marine gravity data collected during 1975 and 1976 have been integrated with U.S. Navy and other available data over the U.S. Atlantic continental margin between Florida and Maine to obtain a 10 mgal contour free-air gravity anomaly map. A maximum typically ranging from 0 to +70 mgal. occurs along the edge of the shelf and Blake Plateau, while a minimum typically ranging from -20 to -80 mgal occurs along the base of the continental slope, except for a -140 mgal minimum at the base of the Blake Escarpment.

Although the maximum and minimum free-air gravity values are strongly influenced by continental slope topography and by the abrupt change in crustal thickness across the margin, the peaks and troughs in the anomalies terminate abruptly at discrete transverse zones along the margin. These zones appear to mark major NW-SE fractures in the subsided continental margin and adjacent deep ocean basin, which separate the margin into a series of segmented basins and platforms. Rapid differential subsidence of crustal blocks on either side of these fractures during the early stages after separation of North America and Africa (Jurassic and Early Cretaceous) is inferred to be the cause of most of the gravity transitions along the length of margin. The major transverse zones are southeast of Cape Fear, east of Cape Hatteras, near Norfolk Canyon, off Delaware Bay, just south of Hudson Canyon, and south of Cape Cod.

Local Airy isostatic anomaly profiles (two-dimensional, without sediment corrections) were computed along eight multichannel seismic profiles. The isostatic anomaly values over major basins beneath the shelf and rise are generally between -10 and -30 mgal while those over the platform areas are typically 0 to +20 mgal. While a few isostatic anomaly profiles show local 10 to 20 mgal increases seaward of the East Coast Magnetic Anomaly (ECMA: assumed to mark the ocean-continent boundary), the lack of a consistent correlation indicates that the relationship of isostatic gravity anomalies to the magnetic anomalies and the ocean-continent transition is variable.

Two-dimensional gravity models have been computed for two profiles off Cape Cod, Massachusetts, and Cape May, New Jersey, where excellent reflection, refraction, and magnetic control appear to define 10 and 12 km deep sedimentary basins beneath the shelf, respectively, and 10 km deep basins beneath the rise. The basins are separated by a 6 to 8 km deep basement ridge which underlies the East Coast Magnetic Anomaly and appears to mark the landward edge of oceanic crust. The gravity models suggest the oceanic crust is between 11 and 18 km thick beneath the ECMA, but decreases to a thickness of less than 8 km within the first 20 to 90 km to the south-east. The crust underlying the sedimentary cover appears to be 12 to 15 km thick on the landward side of the ECMA and gradually thickens to normal continental values of

greater than 25 km within the first 60 to 110 km to the northwest. Multichannel seismic profiles across platform areas, such as Cape Hatteras and Cape Cod, indicate the ocean-continent transition zones there are much narrower than profiles across major sedimentary basins, such as the one off New Jersey.

Published in: Tectonophysics.

Supported by: USGS; ONR Contract N00014-79-C-0071, NR 083-004.

A GEOPHYSICAL ATLAS  
OF THE EAST AND SOUTHEAST ASIAN SEAS:  
FREE-AIR GRAVITY FIELD  
SCALE 1:6,442,199

Anthony B. Watts, Carl O. Bowin  
and John H. Bodine

A new free-air gravity anomaly map of the East and Southeast Asian Seas has been prepared. This map is based on a compilation of gravity measurements obtained at sea and on land which were available up to 1977.

Published in: Geol. Soc. American,  
Map and Chart Series MC-25, 1978.

Supported by: ONR Contract N00014-74-C-262, NR 083-004.

SOUND CHANNEL PROPAGATION  
THROUGH EDDIES SOUTHEAST OF THE GULF STREAM

John C. Beckerle, Lincoln Baxter II,  
Robert P. Porter and Robert C. Spindel

Acoustical signals at 270 Hz from SOFAR floats drifting in the region southeast of the Gulf Stream were recorded during most of 1975 from a near axis sound channel hydrophone near Bermuda. The amplitude levels received exhibit a large increase (12-18 dB) commencing about July 24th following a long period (March to July) of relatively lower peak level amplitudes. The large amplitude increase can be attributed to the influence of a large cyclonic eddy (Gulf Stream ring) that passed slowly between the SOFAR floats and Bermuda. Such an eddy produces a large sound speed anomaly that extends to depths below the axis of the sound channel. On July 24th, two SOFAR floats were known to have approximately the same sound transmission path through the edge of the large eddy. The sound transmission peaks occur when no ocean eddy is between the SOFAR floats and the receiver.

Their spacing shows they occur at regular refraction caustics in the sound channel. When the sound transmission path passes through an eddy, these transmission focal distances may be shifted to greater range and the signal level may be greatly enhanced. At present, only qualitative agreement exists between the acoustic effects of an eddy and the observations.

Supported by: ONR Contract N00014-74-C-0262, NR 083-004.

CLIMATIC CHANGES, MAGNETIC INTENSITY  
VARIATIONS AND FLUCTUATIONS OF THE  
ECCENTRICITY OF THE EARTH'S ORBIT  
DURING THE PAST 2,000,000 YEARS  
AND A MECHANISM WHICH MAY BE RESPONSIBLE  
FOR THE RELATIONSHIP - A DISCUSSION

Alan D. Chave and Charles R. Denham

In several papers Wollin, et al. have suggested that a relationship exists between climate, intensity of the earth's magnetic field, and the eccentricity of the earth's orbit. Using data from deep-sea cores, they noted that natural remanence intensity was low during warm climatic intervals over the past 2 Ma and inferred a qualitative visual correlation with the orbital eccentricity of the earth.

We maintain that no connection is evident between climate and paleointensity of the magnetic field. The result in Wollin, et al. is due to a failure to remove the effect of varying magnetic material input, which is largely climatically controlled. We present evidence from a North Atlantic core that no connection between climate and paleointensity exists over the interval 60,000-127,000 years b.p. and we stress the necessity for careful attention to details of the magnetic character of the sediments in interpreting marine sedimentary paleomagnetic data.

Published in: Earth and Planetary  
Science Letters, 44 (1979) pp. 150-152.

Supported by: NSF Grant DES 77-82255.

LITHOSPHERIC STRUCTURE OF THE WALVIS RIDGE  
FROM RAYLEIGH WAVE DISPERSION

Alan D. Chave

Rayleigh wave group velocity dispersion has been used to study the lithospheric structure along the Walvis Ridge and for a nearby South Atlantic path. Results of a

formal inversion for the ridge suggest crustal thickening to 12.5 km and anomalously low mantle shear velocity of 4.25-4.35 km/sec to depths of 45 km. Lowering the density in this region during inversion does not raise the shear velocity to the oceanic norm. A nearby off-ridge path that covers the Cape Basin and part of the western Walvis Ridge shows no sign of thickened crust. No significant differences from normal oceanic lithosphere exist below 50 km and no signs of thinning of the lithosphere under the Walvis Ridge are apparent. The low mantle shear velocity is consistent with an increase in the mean atomic weight of the mantle material, possibly by iron enrichment.

Published in: J.G.R., Vol. 84, Pg. 6840-6848.

Supported By: NSF Graduate Fellowship and the WHOI Education Office.

THE GALAPAGOS RIFT AT 86°W  
MORPHOLOGICAL WAVE FORMS:  
EVIDENCE FOR A PROPAGATING RIFT

Kathleen Crane

A combination of near-bottom and multi-beam surveys of the N-S spreading Galapagos Rift reveals periodic morphological transitions from highs to lows along fault scarps with amplitudes of 90-140m and wave-lengths of 24-30 km. All fault scarps reflect similar wave forms, yet the highs and lows are offset by a consistent phase shift with each successive increment of time. Fault scarp morphology realigns approximately every 0.33 m.y. This progression along strike, distance, and time infers either postemplacement tectonics resulting from antisymmetric distribution of stresses in young crust, oscillating volcanism, or propagation of a magma chamber(s) along the axis of the spreading center.

In Press: J.G.R.

Supported by: ONP Contract N00014-79-C-0071 NR 083-004.

OBLIQUE ANHYSTERETIC REMANENT MAGNETIZATION

Charles R. Denham

Orientation of the weak biasing field obliquely, rather than parallel, to the strong alternating field causes an oblique anhysteretic remanent magnetization (OARM) which is systematically misaligned with

respect to the bias. Experiments on a deep-sea sediment also showed that with increasing bias angle the intensity of OARM diminishes greatly, the coercive force is slightly lower, and the remanence is monodirectional over all coercive force bands. An adaptation of the Stoner-Wohlfarth mechanism described here may help to explain some fundamental aspects of OARM behavior.

Published in: J.G.R., Vol. 84, No. B11.

Supported By: NSF Grant OCE 77-8255 and ONR Contract N00014-74-C262, NR 083-004.

THE CRUSTAL STRUCTURE OF THE KANE FRACTURE ZONE FROM SEISMIC REFRACTION STUDIES

Robert S. Detrick, Jr. and G. Michael Purdy

A detailed seismic refraction experiment was carried out across the Kane Fracture Zone near 24°N, 44°W using explosive and airgun sound sources and eight ocean bottom hydrophone (OBH) receivers. The shooting lines and receivers formed a 'T' configuration across the fracture zone with two receivers located about 50 km apart in the fracture zone trough and the remaining six receivers positioned 25-30 km apart on either side of the fracture zone. The crustal thicknesses and velocities observed at the receivers located north and south of the Kane Fracture Zone fall within the range of those typically observed for normal oceanic crust (there is no convincing evidence for significantly different crustal thicknesses or upper mantle velocities on either side of the fracture zone) despite a 10 my age difference. Anomalously thin crust is present beneath the Kane Fracture Zone trough with total crustal thicknesses of only 2-3 km, about half the thickness of normal oceanic crust. This crust is also characterized seismically by low compressional wave velocities (~4.0 km/s) at shallow depths and the absence of a normal layer 3 refractor. This anomalous crust extends over a width of at least 10 km and dense, high-velocity mantle type material may also exist at shallow depths beneath the adjacent Kane Fracture Zone ridge.

Results from other geological and geophysical studies of fracture zones suggest that this type of crustal structure may be typical of many Atlantic fracture zones. We propose that the anomalously thin crust found within these fracture zones is a primary feature caused by the accretion of a thinner volcanic and plutonic layer within the fracture zone. This anomalous crust,

which probably is restricted to a zone no wider than a typical transform fault valley (~10 km) in most cases, is inferred to consist of a few hundred meters of extrusive basalts and dikes overlying about 2 km of gabbro and metagabbro, possibly interbedded with ultramafics. This anomalously thin crustal section may be extensively fractured and brecciated at shallow levels by faulting in the active transform domain. A relatively narrow zone of thin crust within fracture zones can explain a number of geological and geophysical characteristics of fracture zones including the depth of the transform fault valley and the exposure of deep crustal and upper mantle rocks in the walls of fracture zones.

Supported by: ONR Contract N00014-74-00262  
NR 083-004.

EVIDENCE FOR CRUSTAL THINNING NEAR FRACTURE  
ZONES: IMPLICATIONS FOR OPHIOLITES

Paul J. Fox, Robert S. Detrick,  
and G. Michael Purdy

Marine geophysical experiments, principally seismic refraction, have defined the first-order velocity structure of the oceanic crust and upper mantle. A diverse range of basaltic rock types have also been recovered from the escarpments which flank ridge/ridge transform faults providing information on the petrology of the oceanic crust and upper mantle. Laboratory studies defining the physical properties of these rocks have enabled investigators to correlate rock types with seismic refraction results providing the constraints needed to construct a generalized geologic model of the oceanic crust. Most investigators believe ophiolites represent slabs of oceanic crust and upper mantle which have been obducted onto continental lithosphere. Our knowledge of the internal constitution of oceanic crust has been greatly enhanced by the structural and petrologic relationships exhibited by ophiolites.

By integrating the results of these various studies the following picture of the oceanic crust has emerged: a disrupted sequence of pillow lavas, massive basalt flows, intercalated sediment and rubble zones, approximately 500m thick, grades into a 1000m to 1500m thick sequence of sheeted dikes. This extrusive and shallow intrusive carapace is underlain by an assemblage of 3 to 5 km of gabbro. At shallow levels the gabbro is isotropic and may include pods of late stage differentiates.

At depth the isotropic gabbro grades into cumulate gabbro and interbedded ultramafic units. Below lie upper mantle rocks characterized by tectonized harzburgite. Metamorphic affects and zones of high strain are distributed heterogeneously through the assemblage.

Our knowledge of the seismic structure of 'normal' oceanic crust remains strongly dependent upon averages or histograms formed from various data compilations. The averaged crustal models derived from these compilations model only the bulk properties of the oceanic crust. Close examination of these data reveal significant variability in both the velocity structure and total thickness of the crust. Part of this scatter may be attributed to inadequacies in the original data or in the assumptions used to interpret these data (plane, dipping layers of constant velocity). However, we believe that a significant portion of this variability is real and reflects the true heterogeneity of the oceanic crust.

Determining the first-order heterogeneities in oceanic crustal structure and relating these changes to crustal age, spreading rates or tectonic regime is essential if we are to build meaningful models of oceanic crustal formation, and if we are to understand the crustal heterogeneities expressed in ophiolites and the tectonic setting they reflect.

In this paper we present several independent lines of evidence which indicate that the existence of a transform fault along a slowly accreting plate boundary (<4 cm/yr) significantly alters the shallow level processes of crustal genesis resulting in anomalously thin oceanic crust.

Supported by: ONR Contract N00014-74-00262  
NR 083-004.

THE HYDROTHERMAL MOUNDS OF THE  
GALAPAGOS RIFT: OBSERVATIONS WITH  
DSRV ALVIN AND DETAILED HEAT FLOW STUDIES

David L. Williams, Kenneth E. Green,  
Tjeerd H. Van Andel, Richard P. Von Herzen,  
John R. Dymond and Kathleen Crane

Ranging in height from gentle hills of less than a meter to steep-sided giants of more than 20 meters, the mounds of the Galapagos Rift are spectacular hydrothermal features. Their internal temperatures have been measured at up to 130°C above the bottom water temperature and total heat flow (conducted plus convected) can be several

hundred to several thousand times the normal oceanic values. Fluids, when they discharge from the mound, do so at a very slow rate and at temperatures probably quite near the bottom water temperature. The mounds are principally composed of iron silicates intermixed and encrusted with lesser amounts of manganese oxides. They are generally found in rows, in a uniformly sedimented area above faults or fractures in the crustal rocks which permit fluids to escape from a deep hydrothermal aquifer. The sediment blanket in some way alters the chemistry of the ascending thermal fluids and leads to the development of mounds. The mounds field, covering an area of at least 200 square kilometers and consisting of thousands of individual mounds, is probably less than 300,000 years old; and many of the mounds may be only a few tens of thousands of years old or less.

Supported by: NSF Grant OCE 77-23470.

THE GALAPAGOS SPREADING CENTER AT 86°W:  
A DETAILED GEOTHERMAL FIELD STUDY

Kenneth G. Green and Richard P. Von Herzen

We report here measurements of the heat flow field of the Galapagos Spreading Center on crust of age less than 1.0 m.y. The 443 measurements covering about 570 km<sup>2</sup> reveal the planform of the conductive flux and permit the first truly areal estimate of the near-axis heat flux for comparison with the theoretical plate cooling models. The intrusion process and associated hydrothermal circulation dominate the surface heat flow pattern, with circulation apparently continuing beyond the limits of our survey. The areal average of the conductive heat flux is  $7.1 \pm .8$  HFU ( $295 \pm 33$  mW/m<sup>2</sup>), about one third the heat flux predicted by plate models. The remaining heat is apparently removed by venting of hydrothermal waters at the spreading axis and through basalt outcrops and hydrothermal mounds off-axis. The pattern of surface heat flux is lineated parallel to the axis and the strongly lineated topography. Sharp lateral gradients in heat flow, greater than 10 HFU/km near escarpments and commonly expressed as high heat flow at the tops of scarps and lower heat flow in the valleys, may indicate a local concentration of the circulation by surface fault systems and/or variable sediment thickness.

Supported by: NSF Grant OCE 77-28281.

RELATIVE RATES OF MOVEMENT  
OF THE OCEAN FLOOR

James R. Heirtzler

Much new data now exists on the long-term geologic motions of the ocean floor. Horizontal motions when averaged over a few million years are approximately 10 to 100 km/m.y. Relative motions across transform faults are twice these values.

Uplift of the ocean crust in the rift mountains may be at a rate of 40 km/m.y. for 1 m.y. old crust, and at a rate of about 02. km/m.y. for 80 m.y. old crust.

Near subduction zones the ocean crust subsides at a rate of 2-4 km/m.y. near the oceanic trench axis and 40-60 km/m.y. on a Wadati-Benioff zone which dips at 45 degrees.

Seamounts subside at a rate of .02-.06 km/m.y. which is comparable to the rate of subsidence due to cooling of the oceanic crustal plates, but two to three orders of magnitude slower than seafloor spreading rates or the subsidence in some Wadati-Benioff zones.

In Press: Marine Geodesy.

Supported by: NSF Grant EAR 78-08082.

MESOZOIC COMPLEMENTARY CRUST  
IN THE NORTH ATLANTIC

Kristin Rohr and Willem Twigt

Mesozoic magnetic anomalies M0 and M4 were surveyed in detail in the North Atlantic Ocean over complementary crustal segments. The relative positions of the North American and African plates for M0 and M4 agree with positions calculated from the regional data set, implying a high degree of plate rigidity.

Supported by: NSF Grant OCE 78-25644.

SHALLOW STRUCTURE AND SEDIMENTATION  
IN THE SOUTHEASTERN MEDITERRANEAN SEA

David A. Ross and Elazar Uchupi

The shallow structure and acoustical characteristics of the southeastern Mediterranean have been studied via a series of 3.5 kHz profiles. Structure and acoustical properties are controlled by three major processes. The most important is the rapid rate of deposition of Nile sediments.

Others are flowage of underlying Messinian salt deposits and compression and tectonics associated with the Mediterranean Ridge.

Supported by: ONR Contract N00014-74-C0262.

#### ZERO OFFSET FRACTURE ZONES

Hans Schouten and Robert S. White

Normal oceanic crust in the North Atlantic is formed in strips typically 50 to 80 km wide separated by fracture zones. Anomalous seismic crustal structure (less than 10 km wide) is found beneath fracture zones regardless of the amount of offset. Although many of these fracture zones exhibit minor and variable offsets in the seafloor spreading magnetic lineations, they separate crust with distinctively different basement morphology and magnetic signatures even when there is no offset apparent in the magnetic lineations. The pattern of both the basement relief and the magnetic anomalies provides the evidence for the persistence of minor and variable offset fracture zones formed by the decoupling of adjacent spreading centers over a period of at least 15 Ma of seafloor spreading despite only small or negligible offsets.

Supported by: ONR Contract N0014-74-C0262 NR 083-004 and NSF Grant OCE 76-22512 A01.

#### MESOZOIC MAGNETIC LINEATIONS IN THE WESTERN NORTH ATLANTIC AND THE MEMORY OF THE ACCRETING BOUNDARY

Hans Schouten and Kim D. Klitgord

A detailed aeromagnetic anomaly contour chart of the Mesozoic seafloor spreading lineations southwest of Bermuda reveals the dominant magnetic grain of the oceanic crust and the character of the accreting boundary at the time of crustal generation. During the period of Mesozoic geomagnetic polarity reversals (equivalent to 1200 kilometers of central North Atlantic seafloor formation), the Atlantic accreting boundary consisted of stationary, elongate, seafloor spreading cells that maintained their independence while only minor and variable spatial offsets existed between adjacent cells. Normal oceanic crustal structure was formed in the spreading center cells, but structural anomalies and discontinuities characteristic of fracture zones were formed at the boundaries between adjacent cells which follow the flowlines of Mesozoic relative plate motion in the central North Atlantic. We suggest that the memory for a stationary pattern of independent spreading-center cells resides at the accreting boundary where the brittle

lithosphere is weakest, and where each spreading-center cell independently goes through its cycle of stress-buildup, stress-release and crustal accretion. During each cycle, the memory of a spreading-center segment is refreshed. The cyclic nature of the geologic processes that occur within each cell may provide the mechanism for maintaining the independence of the adjacent spreading-center cells that show no offset in the Mesozoic magnetic anomaly field.

Supported by: ONR Contract N00014-74-C0262 NR 083-004; NSF Grant OCE 76-22512 A01; and the WHOI Ocean Industries Program.

#### ON THE QUALITY OF SEAFLOOR MAGNETIC ANOMALY SOURCES AND RELATED PROCESSES

Hans Schouten, Charles Denham,  
and Woollcott Smith

The quality of marine magnetic anomaly sources is described with the power-density representation of a stochastic model of random temporal and spatial emplacement of the marine magnetic anomaly source in the oceanic crust. Typical values of seafloor spreading and emplacement parameters define a high fidelity system of recording and sea-surface detection of the geomagnetic field reversals for spreading rates over 20 mm/yr. An analogous stochastic model is developed for the formation of seafloor topography by normal faulting. With the power-density spectrum of this stochastic model it is shown that the random process of normal faulting observed in the inner walls of the FAMOUS rift valley can account for the variance of the adjacent West Rift Mountains topography.

Supported by: ONR Contract N00014-74-C0262 NR 083-004.

#### COMPRESSSIONAL TO SHEAR WAVE CONVERSION IN OCEANIC CRUST

Robert S. White and Ralph A. Stephen

Mode conversion from compressional to shear waves or vice-versa, occurs most efficiently where the seismic wave encounters a large change in seismic velocities over a distance of less than half a wavelength. In the oceanic crust, the interface between water or sediment and the volcanic basement is frequently the site of considerable mode conversion: Firstly, we examine the effect of changes in the sediment and the basement properties on the efficiency of mode conversion over a range of horizontal incident

phase velocities assuming that the interface is a first order discontinuity. We then show, with the aid of synthetic seismograms calculated using the reflectivity method, that a small transition zone over which the velocities increase with depth at the top of the basement may have a considerable effect on the amount of conversion. In particular, small changes in the shear wave velocity structure over depths of around half the shear wavelength markedly change the amplitudes of the variable angle basement reflection and the doubly converted lower crustal shear waves, even though we may only consider compressional waves incident on and returned from the crust. Thus, at typical seismic source frequencies, a change of only a few meters in the shear wave transition zone thickness, although considerably less than the wavelength of an incident compressional wave may greatly alter the resultant compressional wave crustal seismogram.

Supported by: ONR Contract N00014-79-C-0071 NR 083-004.

OCEANIC UPPER CRUSTAL STRUCTURE  
FROM VARIABLE ANGLE SEISMIC  
REFLECTION - REFRACTION PROFILES

Robert S. White

The travel times of reflected and refracted arrivals observed on variable angle seismic profiles can be inverted to produce a first approximation to the variation of seismic velocity with depth. A method is discussed for deducing the interval velocity above a reflector by finding the best match between the observed variable angle reflection travel times and those derived by ray tracing through a series of trial models. Further constraints can be placed on the rate of change of velocity with depth by consideration of the amplitudes of both reflections and refractions. Synthetic seismograms, calculated by the reflectivity method, demonstrate that different kinds of velocity structure in the oceanic volcanic basement layer produce characteristically different variations of amplitude with range. In particular, the exact nature of the shear wave velocity transition at the top of the basement has a marked effect on the compressional wave reflection amplitudes. Pre-critical reflection amplitudes are seen to be generally more sensitive to the velocity structure at the sediment - basement interface than are postcritical reflections, while head wave amplitudes are strongly dependent on the velocity gradient in the upper part of the basement.

The second part of the paper presents an analysis of variable angle seismic profiles obtained over the Madeira abyssal plain in the North Atlantic, using the travel time and amplitude interpretation techniques discussed earlier. It is concluded that the velocity structure of this area of typical oceanic crust comprises a stack of distinct layers within each of which the velocity increases smoothly with depth. An upper basement layer 600 to 700 m thick is a remnant of an originally lower velocity seismic layer 2A which is found on younger crust. Beneath this upper layer the compressional wave velocity increases with a gradient of less than 0.7/s to the base of seismic layer 2. The velocity gradient within the underlying seismic layer 3 is constrained by refraction amplitudes as less than 0.1/s.

Supported By: WHOI Education Office.

P A L E O N T O L O G Y  
A N D S E D I M E N T O L O G Y

THE STATISTICAL PREDICTION OF BEACH CHANGES  
IN SOUTHERN CALIFORNIA

David G. Aubrey, Douglas L. Inman,  
and Clinton D. Winant

Changes in natural sand beaches induced by variations in incident waves were predicted by techniques of linear statistical estimation and empirical eigenfunction analysis. A five-year set of measured beach profiles and wave statistics from southern California constituted the data base for this two-faceted statistical study. First, daily beach profile changes were predicted using four different spectral representations of the wave field. These profile changes were predictable using spectral representations of wave energy, radiation stress, energy flux, and wave steepness. Because of constraints on statistical reliability, a longer data set is required to select one of these as an optimal wave parameterization. Second, weekly beach profile changes were predicted using weekly averaged wave characteristics. Weekly beach changes were predictable using weekly mean and maximum values of wave energy and wave height. The best predictor of those tested was the weekly mean wave energy. When combined with a longshore transport model, this onshore/offshore transport estimator should be applicable to other coastal regions with different beach and wave characteristics.

Supported by: NOAA Grant NA80AA-D-00011.

SEASONAL PATTERNS OF ON/OFFSHORE  
SEDIMENT MOVEMENT

David G. Aubrey

Measurements of beach profiles from Southern California spanning a 5-year period have been examined for temporal changes in beach configuration. On an annual time scale the data suggest two distinct seasonal pivotal points separating eroding and accreting regions. Empirical eigenfunction analysis of combined onshore and offshore profiles shows a pivotal point for seasonal onshore/offshore sediment movement at a depth of 2-3 m below mean sea level and suggests another at a 6 m depth. Analysis of accurate reference rod measurements at 4, 6, 10, 14, and 20 m depths supports the presence of the 6 m pivotal point. A simple model of depth-dependent seasonal sand movement suggests that during initial winter storms, sand is eroded from both the foreshore and from depths of 6-10 m and is deposited in water depths from 2 to 6 m. During less energetic periods, sediment migrates both shoreward (to the beach face) and seaward (to depths of 10 m) from its winter site of deposition (water depths from 2-6 m). This observation of depth-dependent motion contradicts the simple single pivotal point model previously suggested for nearshore seasonal onshore - offshore sediment motion and emphasizes the complexity of nearshore sediment transport. A sediment budget for seasonal onshore/offshore transport, based on the dual pivotal point model, consists of exchanges of 85 m<sup>3</sup>/m of beach length across the 3 m pivotal point and 15 m<sup>3</sup>/m across the 6 m pivotal point. Over a longer time scale (i.e., the entire 5 years of study) the beaches showed no net erosion or accretion, suggesting that this limited coastal region is stable over these short time scales.

Published in: Journ. of Geophys. Rsch.,  
Vol. 84, No. C10, October 20, 1979.

Supported by: NOAA Grant NA80AA-D-00011.

PROCEEDINGS OF A WORKSHOP  
ON COASTAL ZONE RESEARCH IN MASSACHUSETTS  
(NOVEMBER 27-28, 1978)

David G. Aubrey

A workshop on Coastal Zone Research held on 27 and 28 November 1978, at Woods Hole Oceanographic Institution, brought together fifty researchers actively studying physical processes in the Massachusetts coastal zone (Appendix 1). Presentations were given by nearly half of the partici-

pants to acquaint other researchers with their past, present, and future research interests. Summaries of the presentations are included in Appendix 3. Although the scope of the workshop was narrow, emphasizing only selected aspects of coastal zone research, it represented an important attempt to assess our knowledge of physical processes in the nearshore, and to encourage cooperation and communication between scientists.

Two sets of recommendations evolved from the workshop. The first set recommends ways to facilitate scientist - user communication, and provide more rapid dissemination of coastal research results. The second set describes areas of future research in the Massachusetts coastal zone. Neither of the two sets of recommendations is comprehensive: they reflect primarily the opinions and judgements of the workshop participants.

Because of the interest expressed by the participants, the workshop will be held on an annual basis until the need for such meetings disappears. Future workshops may have specific goals, e.g. preparation of coastal erosion maps or historical shoreline change maps. Future meetings may also have more state, federal, and local governmental participants in an effort to foster scientist - user communications.

The workshop was co-sponsored by the Woods Hole Sea Grant Program and Woods Hole Oceanographic Institution. The Woods Hole Sea Grant Program has offered to co-sponsor future Workshops on Coastal Zone Research as part of their continued interest in the Massachusetts coastal zone.

Published In: WHOI Technical Report  
79-40, April 1979.

Supported By: Dept. of Commerce, NOAA  
Office of Sea Grant - 04-8-M01-149  
and the Institution's Marine Policy  
and Ocean Management Program.

TOWARDS A QUATERNARY TIME SCALE

William A. Berggren, Lloyd A. Burckle,  
Maria B. Cita, H. Basil S. Cooke,  
Brian M. Funnel, Steve Gardner, James P. Hays,  
James P. Kennett, Neil D. Opdyke,  
Leo Pantouret, Nicholas J. Shackleton  
and Y. Kuni Takayanagi

Nine first appearance (FADs), 23 last appearance (LADs), and 3 other micropaleontological datums are related to the magnetic reversal, oxygen isotope, and calcite dissolution course fraction time scales to

provide a preliminary basis for subdivision of the Quaternary in deep-sea sediments.

The magnetic reversal, oxygen isotope and calcite dissolution/coarse fraction scales have been correlated by determination on the same core materials, and absolute dates applied by  $^{40}\text{K}/^{40}\text{Ar}$  or  $^{14}\text{C}$  dating of materials in known positions on one or other of these scales.

FADs and LADs have been determined in cores for which either a magnetic reversal, oxygen isotope or calcite dissolution - coarse fraction scale has also been available. Altogether 3 FADs and 5 LADs based on diatoms, 4 FADs and 5 LADs based on calcareous nannoplankton, 1 FAD and 8 LADs based on radiolarians, 1 FAD and 5 LADs based on planktonic foraminifers, 2 acme and 1 ratio reversal datum have been determined, and absolute dates inferred by interpolation from known dates on the reference time scales. Some of the FADs and LADs apply or are synchronous only over limited areas of the oceans, others appear to be synchronous throughout the oceans.

The base of the Quaternary is set at the top of the Olduvai Event at 1.6 my. Four FADs, 12 LADs, 2 acme and 1 ratio reversal datum occur above the base of the Quaternary at an average rate of ca. 1 per 100,000 yrs. Five FADs and 12 LADs are recognized in the 0.8 my interval between the top of the Olduvai Event and the Gauss-Matuyama boundary at 2.4 m.y. at an average incidence of ca. 1 per 50,000 yrs.

In Press: Jour. Quat. Res.

Supported by: NSF Grant OCE 78-19769.

CENOZOIC SEDIMENTATION IN THE CENTRAL NORTH PACIFIC

Bruce H. Corliss and Charles D. Hollister

Two sediment assemblages recovered from a Giant Piston Core reflect the northwest migration of the Pacific Plate through an authigenic sedimentation region south of about  $20^{\circ}\text{N}$ , and a detrital sedimentation region north of  $20^{\circ}\text{N}$ . An absence of hiatuses in this unique Cenozoic section is attributed to the mid-plate location of the core site where bottom water circulation and other geological perturbations are slow, predictable and least intense.

Published in: Nature, 282, 1979, pp. 707-709.

Supported by: Sandia Laboratories.

RESPONSE OF DEEP-SEA BENTHONIC FORAMINIFERAL RESPONSE TO THE DEVELOPMENT OF THE PSYCHRO-SPHERE NEAR THE EOCENE/OLIGOCENE BOUNDARY

Bruce H. Corliss

A dominant feature of present-day thermohaline circulation in the oceans is the production of cold Antarctic Bottom Water (AABW) in the Weddell and Ross Sea and along the continental margin off Antarctica. The initiation of AABW circulation was suggested to have begun near the Eocene/Oligocene boundary with the development of the psychrosphere inferred from ostracode and oxygen isotopic data. The isotopic data recorded a reduction in bottom-water temperatures of about  $4^{\circ}\text{C}$ . The Eocene-Oligocene deep-sea benthonic foraminiferal biostratigraphy of DSDP Site 277 in the southwest Pacific has been compared with an oxygen isotope record to determine the response of the benthonic foraminifera to the development of the psychrosphere. Biostratigraphic ranges of 41 taxa show that 22 taxa have no response to the temperature change, while 19 taxa exhibit first or last occurrences. Twelve first appearances and four last occurrences are recorded before the isotopic change, one first appearance and one last occurrence during the event, and one first appearance and five last occurrences are recorded after the isotopic change. Species that exhibit first and last occurrences are all rare taxa. The temperature drop coincides with a pronounced reduction of *Epistominella umbonifera*, but does not appear to affect the relative abundance of other dominant species. Faunal changes subsequent to the isotopic change appear to have occurred gradually during an interval of several million years until a stable assemblage was established. The faunal changes preceding the isotopic event may reflect the gradual development of the psychrosphere during the Middle-Late Eocene with the isotopic change near the Eocene/Oligocene boundary being an event that marked a threshold in Southern Ocean paleocirculation.

Published in: Nature, 282, pp. 63-67.

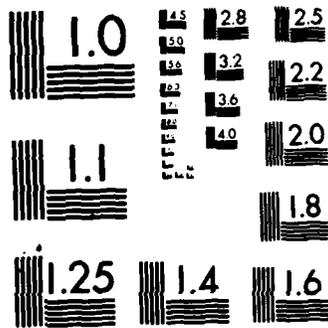
Supported by: NSF Grant OCE 78-119.

A PALEOENVIRONMENTAL MODEL FOR CENOZOIC SEDIMENTATION IN THE CENTRAL NORTH PACIFIC

Bruce H. Corliss, Charles D. Hollister, et al.

A paleoenvironmental model of Cenozoic sedimentation in the central North Pacific





MICROCOPY RESOLUTION TEST CHART  
 NATIONAL BUREAU OF STANDARDS-1963-A

has been constructed from sedimentological, geotechnical and stratigraphic data derived from a single giant piston core collected in the central North Pacific (GPC-3: 30°N, 157°W; 5705 m). This core represents a record of continuous sedimentation for nearly 70 million years. This study is part of a comprehensive program to assess the geologic formations of the mid-plate/-mid-gyre region of the central North Pacific as a possible repository medium for high-level nuclear waste disposal. The core was taken from a region of abyssal hill topography located beneath the present-day carbonate compensation depth. It contains 24.5 meters of undisturbed sediment composed of oxidized brown clay with altered ash layers. Paleomagnetic stratigraphy for the upper 4.5 meters indicates sedimentation rates decreased from 2.5 mm/1000 years at the surface to 1.1 mm/1000 years at 2 Ma. Ichthyolith stratigraphy shows relatively continuous sedimentation rates of 0.2-0.3 mm/1000 years from 65 to 5 Ma. Grains  $> 38 \mu\text{m}$  ( $< 1$  to 2% of the sediment) deposited between 65 and 22 Ma consists primarily of fish debris. Smectite, phillipsite, feldspars, and clinoptilolite predominate in the  $< 20 \mu\text{m}$  fraction. From 22 Ma to the present, the  $> 38 \mu\text{m}$  fraction ( $< 1\%$  of the sediment) consists largely of manganese micronodules, whereas the  $< 20 \mu\text{m}$  fraction consists of quartz, smectite, chlorite, cristobalite, kaolinite, illite, feldspars and mica.

The observed sedimentological variations can be explained in terms of present and past sedimentation patterns in the central North Pacific and by the NNW motion of the Pacific plate during the Cenozoic. Geotechnical properties do not vary monotonically with depth, due to downcore mineralogical variations in the sediment.

The presence of manganese encrusted altered ash layers suggests either manganese precipitation on the ash layers caused by a change in Eh of the sediment due to the ash fall, or perhaps a bottom-water circulation change occurring sometime between 30 and 20 Ma. If a current produced hiatus did occur, the duration is inferred to be less than about 4-5 Ma (or about 1 to 1.5 meters of missing sediment section) due to uncertainties in the ichthyolith stratigraphic technique. The lack of large hiatuses in GPC-3 indicates that this region has been relatively stable during the Cenozoic in comparison to other regions in the Pacific or other oceans where hiatuses of greater than 10 Ma duration are known to exist in the sediment record.

In Press: The Heezen Memorial Volume,  
John Wiley & Sons.

Supported by: Sandia Laboratories.

SURFACE SUSPENDED MATTER OFF WESTERN AFRICA  
RELATIONS OF ORGANIC MATTER, SKELETAL  
DEBRIS, AND DETRITAL MINERALS

Kenneth O. Emery and Susumu Honjo

Components of suspended matter in surface waters between western Africa and the Mid-Atlantic Ridge were removed by filtration and measured by scanning electron and optical microscopy. Skeletal debris from diatoms, dinoflagellates, and other plankton are most concentrated in Antarctic Surface Water and in regions of coastal upwelling. Detrital mineral grains are most concentrated in nearshore regions, from discharge of major rivers, erosion of sea-cliffs, and deposition from offshore winds. Farther offshore are high concentrations of mineral grains brought by trade winds from deserts in both northern and southern Africa. The winds also bring freshwater diatoms and woody tissue.

The remaining component on the filters is marine organic matter, mostly in thin films. These films trap skeletal debris and mineral grains. Presumably, animals that graze upon the films further concentrate the grains into fecal pellets whose rapid settling carries the grains into deeper waters and to the bottom.

The films were found in all other areas of the world ocean from which surface samples were spot-checked: off eastern Asia, off eastern North America, and the central Pacific. Thus they appear to be a major factor in marine sedimentation.

In areas of upwelling off western Africa the total suspended matter in surface waters averages about 0.1 mg/l of filtrate, about five times that present in the open ocean. It consists of about 70% organic matter, 29.6% skeletal debris, and 0.4% mineral grains, in contrast with concentrations in the open ocean of 90%, 8% and 2% respectively.

Supported by: NSF Grant OCE 76-10725.

INDIAN MIDDEN AT QUISSETT

Kenneth O. Emery

A small midden near the head of Oyster Pond was investigated in a salvage operation. It contained mainly shells of quahog, clam and bones of deer, duck, and dog. Indian artifacts included stone and bone arrowheads and tools. Ones of European source were of iron, lead, and china plus clay pipes. The small size of the midden suggests that it was deposited as the residue from a single feast that occurred probably between 1660 and 1765.

Supported by: Bigelow Chair.

Published in: Annual Report 1979, Cape Naturalist, March 1980.

MODIFICATION OF THE OXYGEN-ISOTOPE RECORD IN DEEP-SEA CORES BY DISSOLUTION CYCLES DURING THE PLEISTOCENE

Jonathan Erez

The glacial-interglacial amplitude (GIA) of oxygen-isotope curves in sediment cores from the Atlantic Ocean is much higher than this amplitude in the Pacific. This difference is explained by non-synchronous  $\text{CaCO}_3$  dissolution cycles during the upper Pleistocene that amplify the GIA in the Atlantic and reduce the GIA in the Pacific.

Much of our knowledge on the Pleistocene epoch and its glaciations comes from oxygen isotope studies of foraminiferal skeletons from deep sea cores. In addition to being a powerful stratigraphic tool, the oxygen isotope record provides information on the timing of glacials, sea level fluctuations, paleotemperatures, paleosalinities and ice accumulation and melting during glacials and interglacials. Deep sea cores also display cyclic variation in their  $\text{CaCO}_3$  content. These  $\text{CaCO}_3$  cycles have a periodicity similar to that of the upper Pleistocene glacial--interglacial fluctuations and are probably caused by  $\text{CaCO}_3$  dissolution. The purpose of this article is to show how  $\text{CaCO}_3$  dissolution cycles have modified the oxygen isotope record in deep sea cores.

Supported by: NSF Grant OCE 77-07732.

ISOTOPIC COMPOSITION OF PLANKTONIC FORAMINIFERA IN PLANKTON TOWS, SEDIMENT TRAPS AND SEDIMENTS

Jonathan Erez and Susumu Honjo

Planktonic foraminifera from plankton tows, sediment traps and sediments in the central North Atlantic were studied in order to understand what determines their oxygen and carbon isotope compositions. A clear separation of species and genera on a  $^{18}\text{O}$  vs.  $^{13}\text{C}$  plot for all samples suggests that their isotopic composition is controlled to a certain degree by biological factors. Within a species population, the Globorotaliids show a positive linear correlation between  $^{18}\text{O}$  and  $^{13}\text{C}$ , while the shallow dwelling spinose species, (mostly Globigerinoides species), do not show a definite trend. The latter species, when collected in plankton tows, often show slight negative deviations from isotopic equilibrium with respect to oxygen. All species deviate from carbon isotope equilibrium by (-1.5) to (-6 ‰). These deviations from equilibrium are probably caused by incorporation of isotopically light metabolic  $\text{CO}_2$  into the skeleton, which is enhanced by the activity of symbiotic algae. During their ontogeny the average weight per individual of most species increases which indicates that calcification continues to a depth of about 100m. This additional skeleton (roughly 50% by weight) is isotopically heavier because temperatures are lower and photosynthesis of symbiotic algae stops below the photic zone. Therefore, the skeleton of foraminifera collected in sediment traps below 400m has an overall oxygen isotope composition that seems to be in equilibrium for  $\text{CaCO}_3$  deposited in the upper 100m.

Published in: Stable Isotope and Calcareous Remains in the Ocean, W.H. Berger and A.W.H. Be, eds., Symposium Volume, GSA, San Diego, 1979, Pergamon Press, NY.

Supported by: NSF Grant OCE 77-07732.

**IDENTIFICATION OF GENERIC STUDY AREAS  
FOR THE DISPOSAL OF LOW LEVEL RADIOACTIVE  
WASTE: WESTERN NORTH ATLANTIC OCEAN**

Charles D. Hollister, Elizabeth T. Bunce  
and Richard Chandler

Two sites have been identified in the western North Atlantic as deserving further study as potential low level radioactive waste repositories. This study examines those two areas, one north of Puerto Rico and the other east of Cape Hatteras, in light of various physical and geological parameters, including topography, seismicity, sediment characteristics and deep water circulation. A detailed topographic analysis is offered based on seismic reflection studies and recommendations for confirmatory research are outlined for each site.

Published in: WHOI Technical Report  
79-82, July 1979.

**CALCAREOUS NANNOFOSSILS FROM THE  
UPPER SLOPE OF JAPAN TRENCH (DSDP LEG 56)**

Bilal U. Haq and Margaret Goreau

Calcareous nannofossils were encountered only at one of the sites, (435), drilled during DSDP Leg 56. Cores from Hole 435A yield fairly diverse early and late Pliocene assemblages. The section shows considerable reworking, however. Three to five biostratigraphic datum events provide a reasonable bichronology. The datums range from about 3.3 Ma in Core 11 to about 1.8 Ma in Core 3. Paleobiogeographic data indicates relatively stable and warm climatic conditions in this area in the early Pliocene, becoming more unstable in the late Pliocene when the cosmopolitan species become dominant.

Supported by: NSF Grants OCE 76-21274 and  
OCE 78-19769.

**SEDIMENT TRANSPORT OVER THE  
HATTON AND GARDAR CONTOURITE DRIFTS**

Ian N. McCave, Peter F. Lonsdale,  
Charles D. Hollister and Wilford D. Gardner

The contrasted modes of transport and deposition of sandy and muddy contourites have been examined by hydrographic, photographic, lithologic and seismic data from Hatton and Gardar sediment drifts in the East Reykjanes Basin, northeastern Atlantic Ocean. Gardar Drift is of muddy contourites deposited from Iceland-Scotland Over-

flow Water (ISOW) with a thick and relatively intense nepheloid layer whose particles originate from Iceland. Hatton drift is also mainly of mud, possibly from Rockall Bank, but at its foot a strong north-eastward flowing boundary current moves winnowed foraminiferal sand as ripples and low sand waves. The nepheloid layer on Hatton is locally generated and is mainly in a layer of North Atlantic Deep Water (NADW) contaminated with Antarctic Bottom Water (AABW). This layer with its associated particles spreads across the basin as far as the crest of Gardar Drift. The bottom mixed layer over Gardar is mainly thin (30-40 m) and, following the model of Weatherly and Martin (1978), indicative of depositional shear-stresses ( $u_* < 0.7 \text{ cm s}^{-1}$ ). Currents are less than  $12 \text{ cm s}^{-1}$ . Where the currents are fast (maximum  $23 \text{ cm s}^{-1}$ ) and  $u_* > 0.85 \text{ cm s}^{-1}$  over sands at the foot of Hatton Drift the mixed layer is 89 cm thick, but this thins to less than 40 m higher up on the drift as the environmental changes from winnowing towards deposition of more muddy contourites.

Supported by: ONR Contract N00014-74-C-  
0262 NR 083-004.

**CANYONS OFF NORTHWEST PUERTO RICO:  
STUDIES OF THEIR ORIGIN AND MAINTENANCE  
WITH THE NUCLEAR RESEARCH SUBMARINE NR-1**

Wilford D. Gardner, Linda K. Glover,  
and Charles D. Hollister

The Nuclear Research Submarine NR-1 was used to study morphology, sediment, and sediment-water interactions off the northwest coast of Puerto Rico. New detailed bathymetry from the surface-support ship, USS PORTLAND, shows several submarine canyons in the area, some of them unreported previously. The north coast canyons, Arcibo, Tiberones and Quebradillas, are primarily erosional features although no recent turbidity-current evidence is seen. The canyons are presently filling with river-transported sediments.

High-resolution seismic reflection profiles show the tectonic control of Mona Canyon. Fault zones can be outlined. The effects of sediment input, turbidity currents and bottom currents act to smooth and shape the canyon topography. River alluvium and biogenic debris are draped around the canyon and on the narrow benches between fault scarps on the north wall. Turbidity currents have carried large amounts of sediment from shallow water to the lower reaches of the canyon where the axis is being filled and leveled.

Current measurements from NR-1 show oscillating flow with tidal frequency in the head of Mona Canyon.

Supported by: ONR Contract N00014-74-C-0262 N12083-004.

CUT-OFFS AT AN ABYSSAL MEANDER

Peter Lonsdale and Charles D. Hollister

Reynisdjup Channel is a conduit across the insular rise for turbidity currents from southern Iceland. It has a large meander, at depths of 2000-2200 m, that was examined with a deep-tow vehicle. Erosive turbidity currents are creating cut-off channels by spilling across several parts of the meander. A crevasse at the outside of the bend gives the potential for channel avulsion, and chute cut-off has isolated a scroll bar, but the most drastic effects are at the 8 km wide meander neck, which has been dissected by narrow spillways and by "mega-flutes" up to 1 km wide and 30 m deep.

Supported by: ONR Contract N00014-79-C-0071 NR 083-004.

CONSTRUCTION OF PARFLUX MARK II  
SEDIMENT TRAP: ENGINEERING REPORT

Susumu Honjo and John F. Connell

A large, open ocean applicable sediment trap has been developed at the Woods Hole Oceanographic Institution in order to assess the fluxes of particles sinking through the deep water column, under the sponsorship of the National Science Foundation. PARFLUX Mark II trap, 1978-79 version for PARFLUX phase 1 program, has been successfully operated and has gathered much meaningful data. A trap opening is 1.5 m<sup>2</sup> and consists of 94 hexagonal buffer cells with the nominal form ratio of 2. Sediment particles are concentrated to the receiving cup located at the bottom of the funnel-shaped trap. Two types of receiving cups have been developed; a trap with Type S cup is open at both ends as it sinks to the designated depth. Twenty-four hours after the deployment the receiving cup moves into alignment with the funnel to store the sediment. At the end of deployment an electrical relocater moves the receiving cup, seals the collected sample and leaves the funnel open at both ends while the trap ascends for recovery. Type C mechanism is installed with a shutter which seals the cup during recovery; this type involves a simple mechanism and less moving parts.

Sodium azide/sodium chloride solution is diffused through a series of membrane filters to keep the cup contents in an aseptic condition. We have deployed and recovered 18 traps successfully along with several moorings as deep as 5,600 m for as long as 110 days. This reports the engineering detail and lists the required parts to assist the construction, operation and maintenance of the PARFLUX Mark II sediment trap.

Published in: WHOI Technical Report 79-80, November 1979.

Supported by: NSF Grants OCE 76-82063 and OCE 77-27004.

A FREEZE FRACTURE METHOD; OBSERVATION OF  
FRESH MARINE SEDIMENT UNDER SEM

Susumu Honjo and Margaret Goreau

Fracture surface of freeze-dried, hydrous fine-grained marine sediments involves less chance of fabric disturbance and can be used for meaningful microstructure study under SEM. A small piece of wet core sample is frozen rapidly by liquid nitrogen, fractured and dehydrated in high vacuum, mounted on a large capacity heat sink. The results revealed more realistic spatial relationship of particles and internal structure of larger particles which were not observed by conventional air dried SEM preparation methods.

Supported by: NSF Grant OCE 78-06235.

MATERIAL FLUXES AND MODES OF SEDIMENTATION  
IN THE MESOPELAGIC AND BATHYPELAGIC ZONES

Susumu Honjo

Initial results from samples collected during three sediment trapping experiments at three deep ocean stations in the central Sargasso Sea, the tropical Atlantic and the central North Atlantic are reported in this paper. At each station a moored array with four or five PARFLUX Mark II sediment traps with an opening of 1.5 m<sup>2</sup> was deployed through 4000 m to near bottom for 61 to 110 days. Trapped samples were split by a precision sample splitter into aliquots ranging from 1/4 to 1/256 or smaller and each was analyzed to assess sedimentological properties using microscopic and chemical methods.

The main chemical and mineralogical constituents of trapped sediment were carbonates, silicates and organic compounds. The experiment indicated that the majority

of mass flux to the deep sea was achieved by fast sinking large particles. Dominant large particles were planktonic foraminiferal tests, radiolarian skeletons, pteropod shells, diatom frustules, and fecal pellets of zooplankton.

The fluxes in the layer were essentially constant and consistent in terms of the masses and the constituents at all stations. The mode of sedimentation in the mesopelagic zone was strongly influenced by entrapped zooplankton. The exception was the flux of silicates which increased consistently throughout the entire water column. Biogenic carbonate particles and organic matter contributed 70 to 55% and 10 to 20% of the flux, respectively. The flux of those constituents decreases with depth in the bathypelagic zone due to the post entrapment dissolution. The rate of sedimentation of opal increased with depth in the mesopelagic zone and was constant throughout the bathypelagic zone. On the other hand, the flux of clay particles and quartz/feldspar consistently increased with depth at S<sub>2</sub> and E stations and was small and constant at the P<sub>1</sub> station.

Organic carbon flux near the bottom was estimated to be 0.7, 0.9 and 1.7 mg/m<sup>2</sup>/day at P<sub>1</sub>, S<sub>2</sub> and E stations, respectively. Approximately 6 to 4% and 1.5 to 0.8% of primary production is transported to the mesopelagic and bathypelagic zones, respectively. The C/N ratio of mesopelagic sediment was 8 to 9 and was approximately 10 throughout the bathypelagic zone. The organic carbon atom flux was considerably larger than carbonate carbon in the mesopelagic traps and slightly smaller in the bathypelagic traps.

Supported by: NSF Grant OCE 77-27004.

DEEP OCEAN SEDIMENT TRAP:  
DESIGN AND FUNCTION OF PARFLUX MARK II

Susumu Honjo, John F. Connell and Peter Sachs

In order to assess the fluxes of particles sinking through the deep water column of the open ocean, a large sediment trap has been developed. The trap opening is 1.5 m<sup>2</sup> and consists of 94 hexagonal buffer cells with the nominal form ratio of 2. Sediment particles are concentrated to the receiving cup located at the bottom of the funnel-shaped trap. The trap is open at both ends as it sinks to the designated depth. The receiving cup moves into alignment with the funnel automatically to store the sediment. At the end of deployment an electrical signal moves the receiving

cup again to seal the collected sample and leave the funnel open at both ends while the trap is recovered. Sodium azide-sodium chloride solution is diffused through a series of membrane filters to keep the cup contents in an aseptic condition. We have deployed and recovered 18 traps successfully along with several moorings as deep as 5,600 m for as long as 110 days.

Supported by: NSF Grants OCE 76-10514 and OCE 76-82063.

ACOUSTIC STRATIGRAPHY AND BIOSTRATIGRAPHY  
OF NEOGENE CARBONATE HORIZONS IN THE  
NORTH EQUATORIAL PACIFIC

Robert E. Embley and David A. Johnson

Distinctive acoustic reflectors have been identified and traced over hundreds of km in both low-frequency (air gun) and high-frequency (3.5 kHz) seismic profiles from the region immediately to the north of the Clipperton Fracture Zone in the equatorial Pacific. The reflectors result from impedance contrasts between carbonate-rich layers (up to 90% CaCO<sub>3</sub>) and siliceous clays, and they represent sharp decreases in porosity, increases in wet-bulk density, and decreases in sound velocity. The reflectors have northern limits which increase with increasing age: reflector R0 (late Pleistocene) occurs only south of ~5°N; R1 (upper Miocene) occurs south of ~6°N; and R2 (middle to lower Miocene) extends to at least 10°N. Radiolarian biostratigraphy of the piston cores shows that the most extensive of the reflectors, R2, is clearly time-transgressive within the middle and lower Miocene. The variable geographic extent and the time-transgressive nature of individual acoustic reflectors are in part a consequence of the northward component of motion of the Pacific Plate during the Neogene, with carbonate sedimentation generally restricted to a narrow equatorial region south of ~5°N. There are no detectable unconformities within core intervals corresponding to the 3 major reflectors; hence the reflectors apparently do not represent significant erosional episodes. Superimposed on the effect of plate motion may be an abrupt narrowing of the equatorial productivity belt during the Middle Miocene at 11-12 m.y.b.p. This abrupt transition from carbonate-rich to carbonate-poor sediment over a widespread region corresponds with reflector R2, which is nearly synchronous (11-12 m.y.b.p.) over a span of ~3 degrees of latitude. Similar events may have been responsible for the shallower reflectors R0 and R1.

Supported by: NSF Grant OCE 76-20154.

RADIOLARIAN BIOGEOGRAPHY IN SURFACE  
SEDIMENTS OF THE WESTERN INDIAN OCEAN

David A. Johnson and Catherine Nigrini

Recurrent group analysis of Radiolaria in forty-six core top samples from a north-south transect in the western Indian Ocean has allowed the discrimination of eight distinctive radiolarian assemblages. Most of the designated assemblages have distribution patterns which closely reflect the major oceanographic fronts and first-order patterns of surface water circulation including the South Equatorial Divergence, Subtropical Gyre, Subtropical Convergence, and Antarctic Convergence. An exotic assemblage consisting of four taxa was found off the Arabian coast. These same taxa were previously reported only in the eastern equatorial Pacific, and may be representative of upwelling with relatively restrictive salinities. Radiolarian abundance drops abruptly near 48°S at the Antarctic Convergence, south of which the sediment is a radiolarian-poor diatomaceous ooze.

Supported by: NSF Grant OCE 76-20154.

LATE CENOZOIC SEDIMENTATION AND EROSION  
ON THE RIO GRANDE RISE

David A. Johnson and Christopher S. Peters

The Rio Grande Rise is capped by a thick sequence of pelagic carbonate and reefal sediments, ranging in age from upper Cretaceous to Recent. The north flank of the Rise is dissected by deep erosional canyons which expose the near-horizontally layered calcareous strata as outcrops on the canyon walls. Lithologic and stratigraphic studies of twenty-two piston cores from a small area ( $\sim 25\text{km}^2$ ) on the north flank allow an interpretation of the depositional environment on the Rise during the late Cenozoic, and place constraints on the origin of the erosional canyons. A major unconformity of Pliocene age was penetrated by 12 of the cores. Sediments beneath the unconformity range in age from upper Eocene to lower Pliocene, and correspond approximately in depth with that of equivalent strata recovered at DSDP Site 357 nearby. Pliocene-Pleistocene sediments above the unconformity show systematic regional differences in rate of accumulation, extent of reworking, and the presence of stratigraphic gaps. On the flanks of canyons, an apparently continuous depositional record extends back to  $\sim 370,000$  y.b.p., with some

evidence of effects of winnowing and terrigenous dilution. On the adjacent ridge axes, local variations (on a scale of km or less) in topography or near-bottom flow have created "pockets" of virtually uninterrupted Pliocene-Pleistocene sedimentation separated by regions where Pleistocene sediments are virtually missing. The ridge axes are current-swept today, and contain considerable local variation in sedimentation rates and in the presence of erosional unconformities.

Of several models considered to account for the origin and development of the erosional canyons, the one most consistent with the available lithologic and stratigraphic information includes: (a) initiation of canyon cutting during the late Cretaceous or early Tertiary when portions of the Rise were at or above sea level; (b) deepening of the canyons between the latest Miocene and late Pleistocene via a sequence of erosional episodes alternating with relatively quiescent depositional intervals; and (c) cessation of major canyon cutting in the late Pleistocene ( $\sim 370,000$  y.b.p.).

Published in: Journ. of Geology, 1979,  
Vol. 87, p. 371-392.

Supported by: NSF Grant OCE 74-01744  
and ONR Contract N00014-74-C-0262  
NR 083-004.

DEEP THERMOHALINE FLOW AND  
CURRENT-CONTROLLED SEDIMENTATION IN THE  
AMIRANTE PASSAGE: WESTERN INDIAN OCEAN

David A. Johnson and John E. Damuth

The Amirante Passage is a narrow ( $\sim 100\text{km}$ ) topographic gap near 09°S 52°E, which restricts the northward flow of the deep western boundary current (DWBC) from the Mascarene Basin into the Somali Basin in the western Indian Ocean. A series of NE-NW trending basement ridges divide the passage floor into five major channels whose sill depths (4000-4600m) deepen to the east. Deposition of sediment within these channels below 3800m is controlled by thermohaline flow of the DWBC. The channel axes contain highly reflective, horizontally stratified deposits which have undergone erosion at many locations. In contrast, thick (up to 0.5 sec), acoustically transparent sediment drifts have been deposited along the channel edges and the lower flanks of the adjacent ridges. In the westernmost channel these drift deposits take the form of regular, non-migrating sediment waves with amplitudes up to 100m and wavelengths up to 2 km. Bottom photo-

graphs from the waves show a tranquil sea floor indicative of a depositional environment. In contrast, the adjacent channel axis to the east contains large, asymmetrical ripples and strong current scour, along with the highest nephelometer-measured light-scattering values (suspended particulate matter). These relationships indicate that locally within each channel, DWBC flow is most intense in the channel axis (erosion or non-deposition) but becomes progressively weaker toward the channel edges to the point that deposition generally occurs. On a regional scale, the distribution of sediment-drift deposits vs. channel deposits indicates a western intensification of DWBC flow within the passage even though sill depths are shallowest on the west; the channel deposits (erosional regime) are more widespread on the western side whereas the sediment-drift deposits (depositional regime) are progressively more widespread to the east. At many locations in the eastern channels, drift deposits completely bury channel deposits, suggesting that DWBC flow may have been more intense and of broader regional extent at times in the geologic past. Buried manganese nodules and pavements in the northern Mascarene Basin just south of the Amirante Passage (near 12°S) also suggest possible fluctuations of DWBC flow. The thicknesses of the sediment-drift deposits indicate that thermohaline, current-controlled deposition has been active within the passage for several to tens of millions of years.

Published in: Marine Geology, 33 (1979) 1-44.

Supported by: NSF Grants OCE 76-21522, OCE 76-18049-A01 and OCE 76-22037; and ONR Contract N00014-75-C-0210.

**COCCOLITHOPHORID PRODUCTION  
AND SEDIMENTATION, ROCKALL BANK**

John D. Milliman

Surface waters on Rockall Bank (350 km west of Scotland) during the early summer of 1978 contained concentrations of the coccolithophorid Coccolithus pelagicus (in the palmelloid stage) locally in excess of  $10^6$  coccospheres per liter of water. These values, 1 to 3 orders of magnitude greater than normally expected in the open North Atlantic, reflect the effects of upwelling on the shallower portions of the bank. While high concentrations of coccospheres were restricted to surface waters, near-bottom waters contained abundant coc-

coliths (Emiliana huxleyi) and diatoms, suggesting disaggregation of earlier blooms and/or resuspension of bottom material.

The matrix of the underlying seafloor sediments on the bank becomes increasingly dominated by coccoliths in the deeper portions of the bank. Presumably the decreased effects of winnowing and biologic reworking offset the decreased biologic productivity in offbank waters, resulting in greater retention of coccoliths in deeper water sediments.

Supported by: ONR Contract N00014-79-C-0071 NR 083-004.

**RECENT, TEMPERATE, SUB-PHATIC, CARBONATE  
SEDIMENTATION: ROCKALL BANK, N.E. ATLANTIC**

Terrence P. Scoffin,  
E. Torbjorn Alexandersson,  
George W. Bowes, Julian J. Clokie,  
George E. Farrow and John D. Milliman

Rockall Bank (56°N to 58°N and 13°W to 16°W) is approximately 20,000 km<sup>2</sup> in area and 100 m to 300 m deep, it is effectively removed from present day terrigenous sedimentation by surrounding deep water. Water temperature ranges from 8°C to 12°C. Carbonate sediments presently accumulate on the bank burying Tertiary and older rock outcrops and Pleistocene boulders of glacial origin. Superficial samples were collected by grabbing and dredging and the environments of carbonate production and deposition were observed by underwater television. Component analyses of the sediments indicate a roughly concentric zonation of lithofacies with coarse bryozoan and serpulid remains dominant in the shallow central portion less than 120 m deep; this is surrounded by a zone rich in bivalve and echinoderm fragments and benthic foraminifera which covers the bulk of the bank from depths of about 120 m to 220 m; the peripheral zone below 220 m is dominated by pelagic foraminifera. In water 200 m to 400 m deep, 10 m to 20 m wide patches of 1 m high living colonies of the branched coral Lophelia pertusa abound forming an annular zone around the bank margin. The bulk of the carbonates are calcitic with some aragonitic remains present in the shallow (molluscan) and deep (coral) zones. Microbial borings are rare in the sediments of the agitated waters less than 100 m deep but very abundant in sediments (particularly mollusc, echinoderm and coral) from calmer deep waters. The bioerosion of coral framework is probably

more rapid than the rate of burial of the upright colonies which will lead to their preservation as irregular bands of broken branches. Below 200 m many pelagic tests are filled with diagenetic glauconite and rarely silica, though conspicuous evidence of inorganic carbonate dissolution or precipitation is absent. The carbonate deposits are not very thick but if accumulation continues to keep pace with the subsidence of the bank aphotic temperate limestones will ultimately be formed having a central zone of coarse fragments of benthic organisms rimmed by pelagic deposits containing bands rich in corals.

Supported by: ONR Contract N00014-79-C-0071 NR 083-004.

TEMPORAL AND SPATIAL VARIATIONS IN  
SUSPENDED MATTER IN CONTINENTAL SHELF AND  
SLOPE WATERS OFF THE NORTHEASTERN  
UNITED STATES: GEORGES BANK AND VICINITY

Michael H. Bothner, Carol M. Parmenter  
and John D. Milliman

Seston in waters of Georges Bank originates primarily from biological production and from resuspension of bottom sediments. The highly variable concentrations observed on the central shoals during 10 cruises in an 18-month period are independent of seasons, but the composition shows a weak seasonal correlation. Major storms during any season have the greatest effect on the central bank, raising the concentrations from < 1 mg/l to as much as 4 mg/l. Winter storms produce highest concentrations of noncombustible material throughout the water column, and summer storms appear to increase biological production by mixing additional nutrients into the photic zone. On the southeast flank of the bank, in water depths between 80 and 200 m, both total suspended matter and noncombustible material show little variation compared with the central shoals, and storm effects are far less noticeable.

Highest concentrations (> 15 mg/l) of suspended matter in the entire area, observed in bottom waters south of Nantucket Island after winter storms, appear to have been derived mostly from resuspension of bottom sediment. Resuspended sediment is also common in near-bottom waters of the southwestern Gulf of Maine, and near the intersection of the shelf/slope water mass front and the bottom.

Seasonal variations were observed in the distribution and species composition of

phytoplankton. Coccoliths are predominant on the central bank during the winter, but during the spring and summer they are concentrated on the eastern flank at deeper depths.

Supported by: USGS 14-08-0001-15615.

LATE QUATERNARY PALEO-OCEANOGRAPHY OF  
THE GULF OF AQABA (ELAT) RED SEA

Zeev Reiss, Boaz Luz, Amos Almogi-Labin,  
Ellen Halicz, Amos Winter, M. Wolf,  
and David A. Ross

The quantitative distribution of planktonic foraminifera, pteropods and coccolithophorids, as well as oxygen isotope analyses in 4 deep-sea cores from the Gulf of Aqaba (Elat) and the northernmost Red Sea are summarized. The core record covers about 150,000 years. Detailed stratigraphic subdivision is facilitated by combining all calcareous plankton groups. Time stratigraphic correlation and dating beyond the radiocarbon range are enabled by comparison of the oxygen isotope curves. During the Glacial maximum salinity rose to more than 60 ‰ while winter temperature of the upper waters fell by at least 4°C compared to the present. The rise in salinity can be accounted for by sea-strait dynamics and lowering of sea level. The Gulf of Aqaba and the Red Sea were continuously connected through the Straits of Tiran and there is no indication of dessication during the Glacial maximum.

Supported by: NSF Grant OCE 76-10417.

CHARLIE-GIBBS FRACTURE ZONE: BOTTOM WATER  
TRANSPORT AND ITS GEOLOGICAL EFFECTS

Alexander Shor, Peter Lonsdale,  
Charles D. Hollister and Derek Spencer

Hydrocast sections of the northern valley of the Charlie-Gibbs fracture zone show that below 2000 m this passage through the Mid-Atlantic Ridge is filled mainly with Iceland-Scotland Overflow Water (ISOW). Two current meters moored within this water mass for nine months, at sites just downstream from the 3675 m sill of the passage, recorded mean westerly currents of 3.8 and 4.4 cm s<sup>-1</sup>. These averages include mean westerly velocities of 7-8 cm s<sup>-1</sup> during fall and spring, and almost zero during the winter. Another long-term meter, and an array of meters deployed within 100 m of the sea floor, showed steering of the Overflow Water current by the complex topography near the intersection of the trans-

form fault and the spreading center. West of 35°W a different, denser water mass fills the deepest parts of the valley, below about 3400 m; it is also flowing westward, as shown by meters moored 10 and 20 m above the valley floor for 1.5 to 4 days. However its properties (potential temperature < 2.3°C; salinity < 34.93; oxygen > 6.4 ml L<sup>-1</sup>, silica < 16 μm<sup>3</sup> L<sup>-1</sup>) indicate an origin in the Newfoundland Basin, west of the Mid-Atlantic Ridge. It probably enters the northern valley from the south, via a leak in the bounding transform ridge near 34°30'W, and is entrained westward, back into the western Atlantic, by the overlying ISOW current. The total westward transport across the sill, below 2000m, is estimated at 2.4 x 10<sup>6</sup>m<sup>3</sup>s<sup>-1</sup>. The ISOW carries a significant load of suspended sediment (25μg L<sup>-1</sup>) and there is an intense 100 m-thick bottom nepheloid layer. The seabed, which was examined with a deeply towed instrument package, has been locally scoured downstream from the passage sill, and there are patches of ripples and moated rock fragments. However, most of the floor of the transform valley is a depositional environment.

Supported by: ONR Contract N00014-74-C-0262 NR 083-004.

RECENT PELLETOIDAL CARBONATE SEDIMENTS  
OFF ALEXANDRIA, EGYPT

Peter Stoffers, Colin P. Summerhayes,  
and Janusz Dominik

Sand-sized pellets of aragonite from the continental shelf off Alexandria, Egypt, are modern lithified fecal pellets. They have not been derived from the pseudoolitic coastal limestones, nor are they ooids. We believe they are derived from fresh aragonitic mud with which they are intimately associated. Aragonitic mud is much more common in this area than previous work had suggested.

Supported by: OIP 75-02516 GA 13212.

VERTICAL FLUX OF SEDIMENTARY RADIOLARIA:  
A TAXONOMIC APPROACH TO SEDIMENT TRAP STUDY  
FROM THE WESTERN TROPICAL ATLANTIC

Kozo Takahashi and Susumu Honjo

Radiolarian shells collected by the PARAFLEX E sediment trap experiment at a pelagic station in the western Tropical Atlantic contained 208 species. Their

diversities were probably one of the highest ever reported from a living community. The settling flux rate of individual skeletons was on the order of 10 x 10<sup>3</sup> to 24 x 10<sup>3</sup> shells/m<sup>2</sup>/day. Composition of radiolarian flux changed significantly between 389 and 988 m. This was mainly attributed to the addition of nassellarian populations which dwell in an aphotic deep water layer. The majority of radiolarian shells settle in a single form and apparently reach the sea-floor without substantial modification to the species composition and standing stock. The percent of fragmentation counts of *Psterocorys* is suggested that slow dissolution of radiolarian shells started while descending in the upper water column prior to reaching the bathypelagic zone.

Supported by: NSF Grant OCE 78-27004.

SPATIAL DISTRIBUTION OF STICHLONCHE  
(RADIOLARIA) IN THE EQUATORIAL PACIFIC

Kozo Takahashi and Hsin Yi Ling

A spatial and quantitative investigation of Sticholonche (Radiolaria) from water samples (0 to 800 m depth) in the Equatorial Pacific revealed that: (1) individuals of Sticholonche, (specimens belonging to this genus), constitute a few tens percent of the total radiolarian standing stock, and hence can be regarded as an important marine protozoan group; (2) maximum standing stock occurs between 55 and 110 m depth; and (3) the low standing stock occurs between 200 and 350 m, which coincides with minimum oxygen concentration, (<10 μg-at/l). Evidence suggests that living forms can exist in water depths down to a few thousand meters; however disintegration seems to occur rapidly after death.

Supported By: WHOI Education Office

EARLY TO LATE PLIOCENE CLIMATIC CHANGE  
BASED ON FAUNAL AND OXYGEN ISOTOPIC  
RESULTS FROM THE WESTERN MEDITERRANEAN SEA

L.D. Keigwin, Jr. and Robert C. Thunell

Oxygen isotopic results from Early to Late Pliocene benthonic and planktonic foraminifera from DSDP Site 132, western Mediterranean Sea, show climatic deterioration beginning between 3.2 and 3.0 m.y. ago. Isotopic results on the planktonic foraminiferal species *Globigerinoides ruber* significantly correlate with paleotemperature estimates generated by a transfer function paleotemperature equation. Changes in the

isotopic composition of the benthonic foraminifera *Oridorsalis* suggest significant continental ice began accumulating about this same time.

Supported By: WHOI Education Office -  
Postdoctoral Fellowship.

PLANKTONIC FORAMINIFERAL FLUX TO THE  
DEEP OCEAN: SEDIMENT TRAP RESULTS FROM THE  
EQUATORIAL ATLANTIC AND THE CENTRAL PACIFIC

Robert C. Thunell and Susumu Honjo

The flux of planktonic foraminifera between 100  $\mu$ m and 1 mm to the seafloor has been estimated for the central Pacific (East Hawaii Abyssal Plain) and the equatorial Atlantic (Demerara Abyssal Plain) based on sediment trap samples collected from various water depths. The faunas in each region are quite similar, with 4 or 5 species generally accounting for 70 to 80% of the total assemblage.

At both study sites, the total foraminiferal flux and the carbonate flux tend to decrease with depth. In addition, the flux of individual species of planktonic foraminifera varies significantly with depth, with the number of small, solution susceptible species decreasing with increasing water depth. These results suggest that there is significant dissolution of small (<150  $\mu$ m) foraminifera as they settle through the water column. Material collected from the sediment-water interface directly below the Pacific sediment trap array contains no planktonic foraminifera, suggesting that the residence time of an individual on the seafloor before it dissolves is extremely short.

Supported by: NSF Grants OCE 76-10514,  
OCE 76-82063 and OCE 77-27004.

MODERN BIOGEOGRAPHY OF THE PLANKTONIC  
FORAMINIFERAL FAUNA ASSOCIATED WITH  
LATE QUATERNARY STAGNATIONS OF THE  
E. MEDITERRANEAN

Robert C. Thunell and George P. Lohmann

The deposition of black, organic rich sediments characteristic of anoxic conditions has occurred periodically during the Quaternary within the eastern Mediterranean. The results of previous faunal and isotopic studies suggest that the sapropel layers are related to stagnation caused by a low salinity surface layer. We have attempted to characterize the planktonic foraminiferal

biogeography at times of sapropel deposition during the late Quaternary in terms of the modern distribution of planktonic foraminifera in the Mediterranean Sea. To do this, we first determined the typical planktonic foraminiferal fauna associated with sapropel deposition, then found out where faunas most similar to this sapropel assemblage live in the modern Mediterranean, and then finally determined what is oceanographically unique about those environments. The planktonic foraminifera in 12 sapropel layers were used to define an "average sapropel fauna," its present-day areal distribution was determined by comparing its composition with that of 66 core top samples distributed throughout the Mediterranean. The region where core top faunas are most similar to the "average sapropel fauna" includes the Aegean Sea and the area immediately west of Crete. A comparison of this region of maximum similarity with present-day surface circulation patterns reveals a close association with surface water that flows out of the Aegean and forms a small gyre in the Ionian Sea. One component of this outflowing water is low salinity water derived from the Black Sea. The observed biogeographic pattern of the "average sapropel fauna" supports earlier suggestions that the late Quaternary stagnations of the eastern Mediterranean are related primarily to the input of fresh water from the Black Sea.

Supported by: NSF Grant OCE 77-82149.

P E T R O L O G Y

DSDP LEG 58 ABYSSAL BASALTS FROM THE  
SHIKOKU BASIN: THEIR PETROLOGY AND MAJOR  
ELEMENT GEOCHEMISTRY

Henry J. B. Dick, Nicholas G. Marsh,  
and Thomas D. Bullen

The Shikoku Basin is floored at the three sites drilled during Leg 58 by sill complexes representing widespread "off axis" extensional volcanism. Similar sill complexes also appear to have been drilled during Leg 15 in the Caribbean. At two of the three drill sites the sill complexes were penetrated, and are underlain by intercalated pillow basalts, shallow intrusives, and sheet flows. One differentiated alkali olivine basalt sill was found in the sill complex at site 444. All of the basalts, except the one alkaline sill, appear to be for the most part typical of

mid-ocean ridge tholeiites. Unusual features include very high basalt vesicularities, and therefore primary volatile contents, and a somewhat transitional character in the  $Al_2O_3$ -Feo-MgO discriminant diagram at some sites. The Leg 58 results help define criteria for the identification of back-arc basin ophiolites including: a stratigraphic section with intercalated sills sediments and silicic ash, highly vesiculated basalts, the presence of some basalts with a transitional character between MORB and continental and island-arc basalt suites and an unusual abundance of alkali basalts.

In Press: Initial Reports.

Supported by: NSF Grant OCE 77-26842.

VESCULARITY OF SHIKOKU BASIN BASALT:  
A POSSIBLE CORRELATION WITH THE  
ANOMALOUS DEPTH OF BACK-ARC BASINS

Henry J. B. Dick

High volatile contents at the time of eruption are necessary to explain the vesicularity of Shikoku Basin basalts. A water-rich volatile composition is also indicated by four independent lines of evidence, (1) the large volume of gas required as opposed to the low solubility of gas species other than water in the melt, (2) the vesiculation pattern, atypical of most abyssal tholeiites, which indicates a rapid second boiling on eruption apparently requiring water-rich volatiles, (3) the high  $Fe^{3+}/Fe^{2+}$  ratios indicated by the apparent  $K_D$  for Mg and Fe between olivine and melt, and (4) the absence of significant amounts of phenocrysts in the highly vesicular basalts.

In Press: Initial Reports.

Supported by: NSF Grant OCE 77-26842.

M A R I N E R E S O U R C E S

OPPORTUNITIES AND USES OF THE OCEAN

David A. Ross

The oceans cover about 72 percent of our planet (which is named for the remaining 28 percent). These oceans have fascinated and challenged the human race for centuries. In the past, the ocean had been used first as a source of food, and later as a means of transportation. However, the oceans have recently become very important--they

may offer a solution to many of our modern problems. For example, refuse from land is to be dumped into the ocean never to be seen again; fish and other biological resources are to be caught and used to meet the protein deficiency of the world; oil and gas from the continental shelf and perhaps deeper areas will eventually solve our energy problems. None of these examples is completely possible and the attempt to implement such dreams has already produced severe political, social, and ecological problems in the marine environment. Countries are already planning how the oceans can be divided up so that they will get their "fair share". Economists, politicians, and others are producing almost daily, optimistic or pessimistic views (depending upon your own viewpoint) about the ocean and its resources. Equally loud reports come from environmentalists, conservationists, government sources, and oil companies concerning the pollution and potential destruction of the ocean.

Where is the truth--what are the real problems and opportunities associated with the ocean? This book is written in an attempt to shed some light on how we now use the ocean, what are its opportunities and what we can do in the future. What I am trying to do is present some basic information about the ocean in a form that will be understandable to people who are not oceanographers, but who are interested and concerned about the marine environment.

Publisher: Springer-Verlag New York, Inc., pp. 320.

Supported by: Some support from the Marine Policy and Ocean Management Program, WHOI.

# OCEAN ENGINEERING

OE-1

DEPARTMENT OF OCEAN ENGINEERING  
Earl E. Hays, Department Chairman

## A C O U S T I C S

MEASUREMENT OF THE DIFFERENTIAL  
DOPPLER SHIFT

Ehud Weinstein

Doppler shifts between narrow band signals observed at one or more pairs of receivers and originated from a remote source of radiation are useful for estimating source location and track. This paper deals with an instrumentally attractive approach of estimating differential Doppler shifts by making center frequency measurements at each receiver output and substructuring them in a pairwise fashion. For high in-band signal-to-noise ratios accuracy of the resulting differential Doppler estimate improves with the first power of the signal-to-noise ratio even though the accuracy of each center frequency estimate approaches an absolute upper bound independent of the noise spectrum. For low signal-to-noise ratios center frequency estimates are weakly correlated and their mean square errors add to form the mean square error in the differential Doppler estimate.

Minimum mean square error estimates of the differential Dopplers are obtained by simultaneous processing of all receiver outputs jointly. Comparison between the former and the latter estimation techniques yield some interesting insights: The accuracy of the joint estimation procedure is proportional to  $T^{-3}$  where  $T$  is the observation period. It is basically a coherent procedure. Center frequency measurement and the differential Doppler shift estimate derived from it is basically an incoherent procedure and obeys the well known  $T^{-1}$  dependence. Under high signal-to-noise ratio conditions the estimation error in both procedures decreases with the first power of the signal-to-noise ratio. If the signal-to-noise ratio at each receiver is low but their total sum is high throughout the signal band, the accuracy of the indirect (pairwise) method is degraded by a factor proportional to the inverse first power of the individual signal-to-noise ratio. If the total sum of signal-to-noise ratios does not exceed unity, even in the signal band, one must process all receiver outputs jointly in order to improve otherwise almost certainly poor performance. The array size acts to reduce estimation error by a factor proportional to the number of elements in the receiving array.

Supported by: NORDA Contract N00014-77-C-0196.

ESTIMATION OF DIFFERENTIAL DOPPLER SHIFTS

Peter M. Schultheiss and Ehud Weinstein

If the acoustic signal radiated by a moving source is observed at two or more locations, the received signals exhibit differential Doppler shifts which provide information about source motion. This paper calculates minimum mean square errors for the estimates of differential Doppler shift which can be obtained in a given observation interval. Both Gaussian and sinusoidal signals are considered. The noise is assumed to be Gaussian and independent from sensor to sensor. Dependence of the estimation errors on observation time, signal-to-noise ratio and size of the receiving array are studied. The estimation of differential Dopplers is found to be uncoupled from the estimation of differential delays and from the estimation of signal parameters such as center frequency and bandwidth. A comparison is made between two possible procedures of differential Doppler estimation: Coherent processing of the signals received at two sensors and subtraction of separate frequency estimates obtained at each sensor. The two are equivalent for sinusoidal signals but for large TW Gaussian signals the coherent procedure yields substantially smaller errors.

Published in: J. Acoust. Soc. Am.,  
Vol. 66, No. 5, Nov. 1979.

Supported by: NORDA Contract N00014-77-C-0196.

PASSIVE ARRAY TRACKING OF A CW  
TRANSMITTING PROJECTILE

Ehud Weinstein and Nadav Levanon

Differential Doppler measurements by a passive array are used to track an unstable CW source moving in a ballistic trajectory, e.g. a projectile carrying a proximity fuze. The ballistic equations of motion couple frequency measurements at various sections along the track with the track parameters at any arbitrary time, e.g. at impact.

A non-linear weighted least square method is used to estimate the track parameters, and the resulting error covariance matrix is derived. A numerical example demonstrates the relative contributions of various frequency measurements to the estimation accuracy.

Supported by: NORDA Contract N00014-77-C-0196.

THE CONTRIBUTION OF NORMAL MODES IN THE BOTTOM  
TO THE ACOUSTIC FIELD IN THE OCEAN

Mark K. Macpherson and George V. Frisk

The effects of normal modes in the bottom on the acoustic field in the ocean are examined. The ocean bottom model consists of a slow isovelocity layer overlying an isovelocity half-space to simulate the characteristic sound velocity drop at the water-bottom interface. Attention is focused on the perfectly trapped modes which are excited in the layer by inhomogeneous waves emitted by a point source in the water column. The relative normal mode contribution to the total acoustic field in the water is calculated analytically for a near-bottom source/receiver geometry and evaluated for representative ocean bottom examples. It is shown that, for combined source/receiver heights less than a wavelength, the field is dominated by the leaky mode contribution at short ranges ( $< 2$  km) and the trapped mode contribution at long ranges ( $> 2$  km). For fixed bottom parameters, the trapped mode contribution increases exponentially with decreasing combined source/receiver height. It is also shown that, for a fixed layer wavenumber-thickness produce  $k_1 H$  and fixed layer sound speed, the maximum range at which the leaky modes dominate decreases exponentially with increasing frequency. In fact, the leaky mode fields at different frequencies but equal  $k_1 H$  are approximately exponentially range-scaled versions of the same field with a decay constant that is linearly proportional to frequency.

Supported by: ONR Contract N00014-77-C-0196.

A TECHNIQUE FOR MEASURING THE PLANE WAVE  
REFLECTION COEFFICIENT OF THE OCEAN BOTTOM

George V. Frisk, Alan V. Oppenheim  
and David R. Martinez

A new technique for the measurement of the plane wave reflection coefficient of a horizontally stratified ocean bottom is described. It is based on the exact Hankel transform relationship between the reflection coefficient and the bottom reflected field due to a point source. The method employs a new algorithm for the numerical evaluation of the Hankel transform which is based on the "projection-slice" theorem for the two-dimensional Fourier transform. The details of the algorithm are described in the companion paper. Although the algorithm is applied to the case of an isovelocity ocean, the general theory for measuring the reflection coefficient in a refracting ocean is developed. The method is shown to yield excellent results for synthetically generated data for the case of a hard bottom and slow isovelocity bottom.

The technique provides information about the reflection coefficient not only for real incident angles, but also for complex angles, thus potentially providing substantial additional structural information about the bottom.

Supported by: ONR Contract N00014-77-C-0196; ARPA monitored by ONR under Contract N00014-75-C-0951; NRO49-328.

COMPUTATION OF THE HANKEL TRANSFORM USING  
THE "PROJECTION-SLICE" THEOREM

Alan V. Oppenheim, George V. Frisk and  
David R. Martinez

Two alternative procedures for computing an  $n^{\text{th}}$ -order Hankel transform utilizing the projection-slice theorem for two-dimensional Fourier Transforms are proposed. The algorithms are based on characterizing a circularly symmetric function and its two-dimensional Fourier Transform by a radial slice and interpreting the Hankel transform as the relationship between the radial slice in the two domains.

Supported by: ONR Contract N00014-77-C-0196; ARPA monitored by ONR under Contract N00014-75-C-0951; NRO49-328.

AN UNDERWATER ACOUSTIC PULSE COMPRESSION SYSTEM

R. C. Spindel

This paper describes the signal processing scheme used in sources and receivers for the remote acoustic measurement of the oceanic sound velocity field. Ocean sound velocity varies in response to interior dynamic processes so that a continuous sound field measurement is expected to provide a unique view of physical oceanographic phenomena. The basic signal processing technique uses maximal length shift register sequences with frequency domain (non-power of 2 FFT) matched filtering.

Supported by: NORDA Contract N00014-79-C-0071 and ONR Contract N00014-77-C-0196.

OCEAN ACOUSTIC MONITORING: ACOUSTIC TOMOGRAPHY

Robert C. Spindel

An acoustic method for monitoring mesoscale ocean features over basin wide areas, known as acoustic tomography, is being developed. This paper describes the principles of the technique, and the specialized equipments designed to meet stringent technical requirements. We also present results of recent experiments, forerunners of a full-scale system deployment, that demonstrate the feasibility of the method.

Supported by: NORDA Contract N00014-79-C-0071 and ONR Contract N00014-77-C-0196.

STABILITY AND IDENTIFICATION OF  
OCEAN ACOUSTIC MULTIPATHS

John L. Spiesberger, Robert C. Spindel  
and Kurt Metzger

A phase-coded signal with 64 msec resolution was transmitted at 10 min intervals for a 48 day period between an acoustic source moored at 2000 m depth and a bottom mounted receiver at 3000 m depth and at 900 km range. About 16 multipaths were resolved. They were stable in the presence of ocean fluctuations and could be identified (with some exceptions) from ray theory. The precision to which daily travel time fluctuations along multipaths could be measured was better than 10 msec. The resolution, stability, identification, and precision is adequate for acoustic monitoring of mesoscale ocean variability by measuring travel time variations along ray paths.

Supported by: NORDA Contract N00014-79-C-0071 and ONR Contract N00014-77-C-0196.

C O M P U T E R S C I E N C E

REMOTE BATCH DATA LINK BETWEEN  
VAX 11/780 AND CRAY-1 COMPUTERS

William S. Little

A 4800 baud data communications link between a VAX11/780 computer in Woods Hole, Massachusetts and a CRAY-1 computer in Boulder, Colorado is described. Physical oceanographers at the Woods Hole Oceanographic Institution use their own VAX and the CRAY-1 at the National Center for Atmospheric Research to do numerical modelling of atmospheric and ocean circulation phenomena. Programs, data, and intermediate graphics data are transmitted between the two systems.

Published in: Proceedings of the Digital  
Equipment Computer Users Society,  
San Diego, California, December 1979.

Supported by: Woods Hole Oceanographic  
Institution.

A PDP11-BASED INTERFACE  
BETWEEN AN IBM 1403 LINE PRINTER  
AND AN XDS SIGMA-7 COMPUTER

William S. Little

A PDP11/34-based interface between a Xerox Data Systems Sigma-7 computer and an IBM 1403-3 chain printer is described. The PDP11/34 is connected to the Sigma-7 by means of a synchronous serial data communications channel. The IBM 1403-3 printer is interfaced to the PDP11/34 using a Grumman Data Systems G-1403 line printer controller.

The PDP11/34 partially emulates an IBM 2780 remote batch terminal operating in full duplex mode with an instantaneous data rate of 50k baud. The Sigma-7 emulates an IBM 370 host system.

This indirect interfacing method was selected to make the remote batch station easily expandable to include "foreign" disk and tape support for the Sigma-7, and to make the system easily transferable to any successor to the Sigma-7.

Published in: Proceedings of the Digital  
Equipment Computer Users Society,  
New Orleans, Louisiana, April 1979.

Supported by: Woods Hole Oceanographic  
Institution.

VAX 11/780 COMPUTER GRAPHICS AT THE  
WOODS HOLE OCEANOGRAPHIC INSTITUTION

William S. Little

This paper describes the computer graphics hardware and software that are installed on the VAX11/780 computer at the Woods Hole Oceanographic Institution. Physical oceanographers and geophysicists use Tektronix terminals, a Calcomp plotter and an Imlac refresh graphics terminal to assist in numerical modeling and data analysis efforts. Graphics software from the National Center for Atmospheric Research has been implemented on the VAX. Some device independent graphics capabilities, as well as compatibility with graphics on NCAR's CRAY-1 computer, have been achieved.

Published in: Proceedings of the Digital  
Equipment Computer Users Society, New  
Orleans, Louisiana, April 1979.

Supported by: Woods Hole Oceanographic  
Institution.

OCEANOGRAPHIC USES OF THE VAX 11/780 COMPUTER

William S. Little

This paper describes some of the numerical modeling and data analysis being performed on the new VAX11/780 computer at the Woods Hole Oceanographic Institution. The research efforts of two geophysicists who are studying plate tectonics are described. G. M. Purdy does seismic refraction modeling and data analysis. C. Bowin conducts world-wide gravity and bathymetry studies. Some of the work on ocean circulation of two physical oceanographers is also explained. D. B. Haidvogel numerically models mesoscale eddies in an idealized ocean. W. B. Owens studies vorticity balance using data from deep-ocean current meters. All four scientists rely heavily on the use of FFT's and computer graphics.

Published in: Proceedings of the Digital Equipment Computer Users Society, New Orleans, Louisiana, April 1979.

Supported by: Woods Hole Oceanographic Institution.

DATA COMMUNICATION FEATURES OF THE VAX 11/780 COMPUTER, SIGMA 7 COMPUTER AND DIMENSION 2000 PBX

William S. Little

The data communications configuration of the VAX11/780 Computer System is described. Information on each of the time-sharing terminals, and graphics devices is presented.

Brief update reports on both the Sigma-7 time-sharing configuration and the new telephone PBX are also included.

## TECHNICAL MEMORANDUM

Supported by: IPC Cost Centers 5601 and 5604.

INTERFACE BETWEEN XDS SIGMA 7 COMPUTER AND IBM 1403-3 LINE PRINTER

William S. Little

A mini-computer based synchronous serial interface between an IBM 1403 line printer and the Xerox Data Systems Sigma-7 time-sharing computer is described. The printer subsystem acts like a locally connected remote batch terminal. The hardware and software components are discussed, as are operating procedures and suggested system improvements.

## TECHNICAL MEMORANDUM

Supported by: Woods Hole Oceanographic Institution.

## GENERAL

DESIGN CURVES FOR OCEANOGRAPHIC PRESSURE RESISTANT HOUSINGS

Arnold G. Sharp

Curves are presented for the design of externally-pressurized cylindrically and spherical vessels and for flat end caps. The plots show wall thickness/diameter ratio as a function of collapse depth. Curves are included for the commonly used stainless steels and alloys of aluminum and titanium. Also, there is a brief discussion of the equations on which the plots are based.

## TECHNICAL MEMORANDUM

Supported by: ONR Contract N00014-73-C-0097; NR 265-107.

SHIP TRAFFIC THROUGH GIBRALTAR STRAIT

James W. Mavor, Jr.

A recent oceanographic cruise of the Spanish research vessel, B. O. Cornide de Saavedra, provided a suitable platform from which to survey ship traffic through the Strait of Gibraltar covering several days. This was long enough for a representative sample to be taken, 472 ships. It was observed that only 65% of the ships passing through the strait observed the traffic lanes presented on published navigational charts, i.e. keep to the right. The current structure of the Alboran Sea may offer economic advantage to a different traffic convention. The present mean traffic is 5.8 ships per hour which represents a density greater than that of the Strait of Dover. This suggests that traffic regulation, in the interests of preventing loss of life and oil spills, may be necessary in the near future, particularly when the Suez Canal has been opened to larger tankers.

Traffic is broken down by ship type, course, tonnage, position and time of passage and presented with the aim of assessing the risk of collision. Particular attention is paid to tankers, which represent 60% of the tonnage, and the opportunities afforded for collision on opposite courses. The risks to life and of oil spill are related to the data presented. It is observed that approximately 500,000 tons of oil presently enter the Mediterranean Sea from all sources. This could be doubled by two disasters involving tankers of 250,000 dwt.

Supported by: NOAA Grant 04-8-M01-117.

## G E O L O G Y

DECOUVERTE PAR SUBMERSIBLE DE SULFURES  
POLYMETALLIQUES MASSIFS SUR LA DORSALE  
DU PACIFIQUE ORIENTAL,  
PAR 21°N (PROJET RITA).

CYAMEX Scientific Team (Jean Francheteau,  
Robert D. Ballard, et al.)

Massive zinc, copper and iron sulfide ore deposits have been found at the axis of the East Pacific Rise. Although several investigators had predicted their presence on the deep-ocean floor, there was no supporting observational evidence. The East Pacific Rise deposits represent an appealing modern analogue of Cyprus-type ores associated with ophiolitic rocks on land. They contain up to about 29% zinc metal and up to at least nearly 3% metallic copper. Their discovery will provide a new focus for deep-sea exploration, leading to new assessments of the concentration of noble metals in the upper layers of the oceanic crust.

Published in: C. R. Acad. Sc. Paris,  
t. 287, December 1978.

Supported by: NSF IDOE Grants OCE-78-  
01664 and 78-21082.

HOT SPRINGS AND GEOPHYSICAL EXPERIMENTS  
ON THE EAST PACIFIC RISE

RISE Project Group (F.N. Spiess,  
R. Ballard, et al.)

Hydrothermal vents jetting out 400°C water have been discovered on the axis of the East Pacific Rise. The hottest vent waters issue from mineralized chimneys and are blackened by sulfide precipitates. These hydrothermal springs are the sites of actively forming massive sulfide mineral deposits. Cooler springs are clear to milky and support exotic benthic communities of giant tube worms, clams, and crabs similar to those found at the Galapagos spreading center. Four prototype geophysical experiments were successfully conducted in and near the vent area; seismic refraction with both sources (ALVIN thumper) and receivers on the sea floor, on-bottom gravity measurements, in situ magnetic gradiometer measurements from ALVIN over a sea floor magnetic reversal boundary, and an active electrical sounding experiment. Objectives of the experiments are high resolution determinations of crustal properties along the spreading center leading to knowledge of the source of new oceanic crust and marine magnetic anomalies, the nature of the axial magma chamber and the depth of hydrothermal circulation.

Published in: Science

Supported by: NSF IDOE Grants OCE-  
78-01664, 78-21082 and 79-09984.

HYDROTHERMAL HEAT FLUX OF THE "BLACK SMOKER"  
VENTS ON THE EAST PACIFIC RISE

Ken C. Macdonald, Keir Becker, F. N. Spiess  
and R. D. Ballard

Active hydrothermal vents have been discovered on the East Pacific Rise at 21°N. The most spectacular of the vents jet out 350° - 400°C water at flow rates of meters per second. The heat loss associated with a single vent of this type is two to eight times the total theoretical heat loss for a 1 km segment of ridge out to 1 m.y. age. This underscores the importance of hydrothermal circulation in the heat budget of mid-ocean ridges, but also requires that vents of this type be extremely short-lived.

Supported by: NSF IDOE Grants OCE-78-  
01664, 78-21082 and 79-09984.

MASSIVE DEEP-SEA SULPHIDE ORE DEPOSITS  
DISCOVERED ON THE EAST PACIFIC RISE

CYAMEX Scientific Team  
(Jean Francheteau, Robert D. Ballard, et al.)

Massive ore-grade zinc, copper and iron sulphide deposits have been found at the axis of the East Pacific Rise. Although their presence on the deep ocean-floor had been predicted there was no supporting observational evidence. The East Pacific Rise deposits represent a modern analogue of Cyprus-type sulphide ores associated with ophiolitic rocks on land. They contain at least 29% zinc metal and 6% metallic copper. Their discovery will provide a new focus for deep-sea exploration, leading to new assessments of the concentration of metals in the upper layers of the oceanic crust.

Published in: Nature, Vol. 277, No. 5697.

Supported by: NSF Grant OCE-78-01664.

SUBMARINE THERMAL SPRINGS ON THE GALAPAGOS RIFT

John B. Corliss, et al.

The submarine hydrothermal activity on and near the Galapagos Rift has been explored with the aid of the deep submersible ALVIN. Analyses of water samples from hydrothermal vents reveal that hydrothermal activity provides significant or dominant sources and sinks for several components of seawater; studies of conductive and convective heat transfer suggest that two-thirds of the heat lost from new oceanic lithosphere at the Galapagos Rift in the first million years

may be vented from thermal springs, predominantly along the axial ridge within the rift valley. The vent areas are populated by animal communities. They appear to utilize chemosynthesis by sulfur-oxidizing bacteria to derive their entire energy supply from reactions between the seawater and the rocks at high temperatures, rather than photosynthesis.

Published in: Science, Vol. 203, No. 4385.

Supported by: NSF Grant OCE-77-23978.

#### I N S T R U M E N T A T I O N

##### A TOWED, MULTI-FREQUENCY H. F. SONAR SYSTEM FOR SCATTERING AND OCEAN DYNAMICS STUDIES

F. R. Hess and M. H. Orr

The system described provides wide operational flexibility at any operating frequency from 5 kHz to over 800 kHz (except for a small band around 455 kHz) limited mainly by the availability of transducers. Variable pulse width, variable receiver bandwidth, low receiver noise, various time variable gain functions and wide system dynamic range characterized the system. Built-in time-sharing controls maximize flexibility of graphics display on either dry-paper or fibre-optic CRT recorders.

##### TECHNICAL REPORT

Supported by: NORDA Contract N00014-77-C-0196 and NOAA 04-8-M01-43.

##### A WIDE RANGE SONAR SYSTEM FOR OCEANIC INVESTIGATIONS

F. R. Hess and M. H. Orr

A modular, multi-channel sonar system capable of operation over the range from less than ten kilohertz to over one megahertz is described. The system features large dynamic range, low electronic noise level, variable output power to over one kilowatt and digital control of transmit and receive frequency. Capable of operation with a wide variety of transducers with only matching network changes, the system has found especial utility in acoustic studies of midwater scattering and mixing phenomena in both coastal and open ocean environments.

Data is shown typical of the phenomena amenable to acoustic examination with the system. Waste dump dispersion, internal waves, shear instabilities and particulate transport observations are shown.

Published in: Proceedings of Oceans '79, IEEE Conference on Ocean Engineering, September 1979.

Supported by: NORDA Contract N00014-77-C-0196 and NOAA Contract 04-8-M01-43.

##### STUDY OF CTD CABLES AND LOWERING SYSTEMS

H. O. Berteaux, R. G. Walden, D. A. Moller and Y. C. Agrawal

This study first reviews both the electrical and mechanical modes and causes of failure of electromechanical (E/M) cables used to lower deep sea sensors, such as CTD instruments, from oceanographic ships.

It then outlines measures or steps that could be taken to correct some of the deficiencies observed and improve the systems presently used. These measures include quality control, tests, operational limits, improved handling and maintenance, improved machinery.

The study then surveys alternative cables for lowering the sensors and convey the information from the sensors back to the ship. These alternatives include strength members other than steel (Kevlar), signal carriers other than conventional copper conductors (fiber optics).

The final section - Conclusions - summarizes the recommendations, based on this study, for improving the reliability of present and future CTD lowering systems.

Supported by: ONR Contract N00014-76-C-0197; NR 083-400.

##### A MEMODYNE 3722 CASSETTE READER SYSTEM FOR THE HP 2100 COMPUTER AND PROGRAM CARP

W. E. Terry

This report describes a special purpose electronic interface between the Memodyne 3722 High Speed Cassette Tape Reader and the Hewlett Packard 2100 series computer with program CARP using an HP 12566 interface. A description of the operation and alignment procedures is included.

##### TECHNICAL REPORT

Supported by: ONR Contract N00014-76-C-0197; NR 083-004.

THE INVERTED ECHO SOUNDER

David S. Bitterman, Jr. and D. Randolph Watts

The Inverted Echo Sounder (IES) is an ocean bottom moored instrument which very accurately measures the time required for an acoustic pulse to travel from the bottom to the ocean surface and back. The round-trip acoustic travel time varies in response to changes in the mean temperature structure in the water column above the instrument, which in turn may be used as a sensitive indicator of the shifting paths of ocean currents in many locations.

The instrument is housed in a 17" diameter glass sphere and carries all the necessary control, transmit and receive electronics, a digital cassette recorder and an acoustic release receiver. It can operate in water depths to 6700 m for periods of up to one year and requires no additional mooring equipment other than an anchor.

Records from four IES's deployed under the Gulf Stream northeast of Cape Hatteras are shown along with steps in the processing of the data.

Published in: Proceedings of Oceans '79, IEEE Conference on Ocean Engineering, September 1979.

Supported by: NSF Grant OCE 76-05543.

A NEW UNDERSEA GEOLOGICAL SURVEY TOOL: ANGUS

J. D. Phillips, A. H. Driscoll, K. R. Peal, W. M. Marquet and D. M. Owen

A towed, near-bottom survey system termed ANGUS (Acoustically-Navigated Geological Undersea Surveyor) has been developed for geological and geophysical studies in the median rift valley of the Mid-Atlantic Ridge. System communication is solely acoustic and incorporates a relay transponder attached to either a camera fish, rock dredge, corer, or heat probe device with a shipboard transducer and a seafloor transponder array. The devices can be located with a precision of 5 to 10 m along a simultaneously collected high-resolution bathymetric profile. Automatic digital computer processing of the acoustic navigational information permits real-time monitoring of the path of the device on shipboard graphic display units. Approximately 60,000 high-quality photographs, 70 rock dredges, and 100 heat-flow observations have been collected and related to seafloor features with relief as small as 20 to 30 m. The basic camera fish allows for the addition of other geophysical instruments. Also, expendable sonobuoys have been positioned precisely to locate micro-earthquakes.

Published in: Deep-Sea Research, Vol. 26A

Supported by: NSF Grant GA-35976, GX-36024 and ONR Contract N00014-74-C-0262; NR 083-004.

SHIPBOARD METEOROLOGICAL DATA SYSTEM

Kenneth R. Peal

This paper describes a shipboard system which records true wind as averaged north and east vectors every six minutes on digital tape. Also recorded are air temperature, sea surface temperature, dew point, solar radiation, and ship speed and heading. In addition to recording the data, the system provides a continuous TV-type display of quantities in engineering units at a central location on the ship.

Since the system is computer controlled and programmed in the BASIC language, it can be easily expanded and reconfigured for different applications.

An extensive data set taken manually on the R/V ATLANTIS II JASIN cruise and from a nearby moored buoy is compared with the computer-acquired data set to verify the quality of the latter.

Published in: Proceedings of Oceans '79, IEEE Conference on Ocean Engineering, September 1979.

Supported by: NSF Grants OCE 77-25803 and OCE 76-80174.

## O C E A N D Y N A M I C S

REFRACTIVE MICROSTRUCTURE FROM DIFFUSIVE AND TURBULENT OCEAN MIXING

Albert J. Williams III

Small scale fluctuations in refractive index can affect visibility and image quality in ocean optics. Such fluctuations are a result of temperature and salinity microstructure. Ocean mixing proceeds by the stirring together of dissimilar water types at finer and finer scales until diffusion creates a water type intermediate to the original components. Optically, the most important scale in the mixing cascade is microstructure because it consists of the highest gradient and smallest scale structures. Two classes of mixing process have been distinguished by shadowgraph images made in conjunction with profiles of temperature, salinity, and velocity shear. One class is diffusive and depends on the vertical distribution of temperature and salinity. The other class is turbulent and depends on velocity shear.

Published in: Optical Engineering  
( in press).

Supported by: ONR Contract N00014-79-C-0071.

ARCHIVED TIME-SERIES OF ATLANTIC OCEAN  
METEOROLOGICAL VARIABLES AND SURFACE FLUXES

Andrew F. Bunker and Roger A. Goldsmith

Time-series of monthly averages of latent, sensible and radiational heat fluxes and momentum fluxes at the surfaces of the North and South Atlantic Oceans were calculated from ship weather observations. These fluxes, together with values of meteorological variables have been averaged over entire Marsden squares (10x10° squares) for all months from January 1948 through December 1972. The method of computing fluxes from ship weather observations, listing of variables averaged, addition of sea-ice coverage of sub-polar regions, correction of albedos for the presence of sea ice, correction of infrared radiational exchange for humidity conditions of the upper atmosphere, and format of the data on magnetic tapes are described. Statistics of the fluxes and variables have been computed. Standard data tapes containing these time series and statistics are available.

TECHNICAL REPORT

Supported by: NSF Grant ATM 77-01475 A01.

WOODS HOLE OCEANOGRAPHIC INSTITUTION COLLECTION  
OF CLIMATOLOGY AND AIR/SEA INTERACTION  
(CASI) DATA

Roger A. Goldsmith and Andrew F. Bunker

Scientists at Woods Hole routinely collect and analyze a considerable amount of data relating to the oceans of the world. Of the many different kinds of data, one particular subset concerns those events occurring at the sea surface. A large number of sea surface environmental observations have been collected at Woods Hole. These data, and the subsequent analyses generated from the Air/Sea Heat Flux and the Climatology study projects, have been collected and archived. This document describes the W.H.O.I./Climatology and Air/Sea Interaction (WHOI/CASI) data collection and provides an initial index to its various components.

TECHNICAL REPORT

Supported by: ONR Contract N00014-74-C-0262; NR 083-004 and NSF Grant ATM 77-01475.

S T A T I S T I C S

DECENTRALIZATION OF THE GAUSSIAN MAXIMUM  
LIKELIHOOD ESTIMATOR AND ITS APPLICATIONS  
TO PASSIVE ARRAY PROCESSING

Ehud Weinstein

In radar and sonar the trajectory of a radiating source can be estimated by measuring the relative travel time of the signal to several spatially separated receivers. A maximum likelihood estimate is achieved by simultaneous coherent processing of all receiver outputs. A considerable simplification in estimator structure, and therefore in processor complexity, is obtained by pairwise processing of the receiver outputs. In this paper we determine the performance degradation incurred by decoupling the estimation procedure in such fashion. We show that if the in-band signal-to-noise ratio is much greater than unity for all receivers pairwise processing is nearly optimal. If the in-band signal-to-noise ratio falls below unity but the product of signal-to-noise ratio and the number of receivers is large then simultaneous coherent processing yields a level of performance equal to that of pairwise processing with unit signal-to-noise ratio. If the product of signal-to-noise ratio and the number of receivers falls below unity, pairwise processing seriously degrades performance. Finally we note that decentralizing estimator structure is a powerful technique that may be used to simplify processor complexity whenever large data vectors and/or large parameter sets must be processed.

Published in: IEEE Trans. on Acoustic  
Speech and Signal Processing.

Supported by: NORDA Contract N00014-77-C-0196.

SPERM WHALE POPULATION MODEL

William S. Little

This paper describes a computer program that simulates the population dynamics of sperm whales. The movement of male whales in search of pods (herds of females and young) in an idealized rectangular ocean is modelled. The population

is subjected to various rates of mortality due to hunting and to natural causes. The model attempts to show a relationship between geographic distance and whale population decline under certain management policies (kill quotas). Whale migration can be displayed on a graphics CRT.

Published in: Proceedings of the Digital Equipment Computer Users Society, San Diego, California, December 1979.

Supported by: Marine Biological Laboratory.

SURVEY DESIGN IN THE MARINE ENVIRONMENT:  
THREE EXAMPLES

Woolcott K. Smith

Three examples are used to illustrate the range of statistical design problems encountered in marine research. The first example uses non-linear design methods to find the optimum survey pattern for accurately locating the positions of acoustic beacons used in precision navigation. In the second example time series methods are used to evaluate environmental survey designs and to determine the number of times to repeat a survey over time. In the third example we show that a variation of double sampling procedures can be implemented quickly in response to an oil spill, providing greater flexibility in evaluating the effect of the oil spill.

Published in: Advanced Concepts in Ocean Measurement (eds. F. P. Deemer, F. J. Verberg and D. Z. Merkes).

Supported by: NOAA Sea Grant 04-8-M01-149.

DIVERSITY AS AN INDICATOR OF POLLUTION:  
CAUTIONARY RESULTS FROM MICROCOSM EXPERIMENTS

Woolcott Smith, Victoria R. Gibson, Susan Brown-Leger and J. Frederick Grassle

Data from two microcosm experiments (CEPEX and MERL) are examined to determine whether diversity measures can provide an appropriate indicator of environmental stress. It is concluded that diversity is a rather stable community parameter, relatively insensitive to both natural variation and pollution over the short-term. When a community is not in stationary equilibrium with its environment it appears that changes in species composition and density are a more reliable indicator of stress than diversity measures.

Supported by: NSF/IDOE Grant OCE 77-27446; EPA Grant R8039020; and NOAA Sea Grant 04-8-M01-149.

AN OIL SPILL SAMPLING STRATEGY

W. K. Smith

A strategy for oil spill surveys is outlined. It depends on oversampling in the first survey, and recording easy-to-measure variables associated with each sample. In the second stage, the samples are subsampled for the more expensive and time-consuming biological and chemical analysis. This procedure is an extension of double sampling. This kind of survey is easy to implement on short notice and, because it is based on classical sampling theory, the survey's results should be relatively easy to defend in administrative and legal proceedings.

Published in: Sampling Biological Populations (eds. R. M. Cormack, G. P. Patil and D. S. Robson), International Statistical Ecology Program.

Supported by: NOAA Sea Grant 04-8-M01-149.

# PHYSICAL OCEANOGRAPHY

P0-1

DEPARTMENT OF PHYSICAL OCEANOGRAPHY  
Valentine Worthington, Department Chairman

## OCEAN CIRCULATION

THE BETA SPIRAL IN THE NORTH ATLANTIC  
SUBTROPICAL GYRE

David W. Behringer and Henry M. Stommel

The results of the first hydrographic cruise specifically designed to test calculations of the  $\beta$ -spiral are discussed. The method, first proposed by Stommel and Schott, permits the computation of absolute geostrophic velocities from observations of density alone. Several variations on the basic calculations were used and all gave consistent results. Sensitivity of the results to variations in the depth range of data used in the calculations, a problem with earlier calculations based on historical data, was not a problem with these data. Comparisons of the new  $\beta$ -spiral are made with  $\beta$ -spirals computed from historical data and with the results of a separate calculation using the inverse theory discussed by Wunsch.

Supported by: NSF Grant OCE78-18460.

HEAT TRANSPORT BY CURRENTS ACROSS  
25°N LATITUDE IN THE ATLANTIC OCEAN

Harry L. Bryden and Mindy M. Hall

Heat transport by currents across 25°N latitude in the Atlantic Ocean is estimated from existing oceanographic measurements to be  $1.1 \times 10^{15}$  W northward. Such transport agrees within estimated error with the value obtained from charts of energy exchange between ocean and atmosphere but is a factor of two smaller than the recent value derived from satellite radiation measurements.

In press: Science.

Supported by: W.H.O.I. Summer Fellowship and NSF Grants OCE77-19403 &amp; OCE77-22887.

DEEP AND BOTTOM WATER  
IN THE CHARLIE-GIBBS FRACTURE ZONE

John G. Harvey

Historical temperature and salinity data from the Charlie-Gibbs Fracture Zone, including some 100 occupations of Ocean Weather Station "Charlie", have been examined. The spatial distribution and the seasonal and year-to-year variations between 1964 and 1973 of the value of the deep salinity maximum, which is taken to be indicative of the core of Iceland-Scotland overflow water, are presented. The density fields at 2500 and 3500 m are compared and the characteristics

and distribution of the bottom water are considered.

Supported by: Grants from the Leverhulme Trust and Royal Society (United Kingdom).

TRITIUM IN THE DEEP NORTH ATLANTIC OCEAN

William J. Jenkins and Peter B. Rhines

A distinct core of tritium (from nuclear weapons testing in the atmosphere) marks the southward flowing jet of the deep western boundary current of the North Atlantic circulation at 30°N latitude. The concentrations, ca. 0.5 to 1.0 T.U. (1 Tritium Unit = one  $^3\text{H}$  atom per  $10^{18}$  H atoms), indicate a roughly ten-fold dilution of source waters north of the Grand Banks. This thin jet, or order 50 km in width, carries water from northern sources into regions which, until recently, were free of anthropogenic tritium. It underlies the more extensive distributions of tritium found in recently renewed waters above the thermocline.

Supported by: ONR Contract N00014-76-C-0197, NR 083-400 and NSF Grants OCE76-81774 &amp; OCE76-81190.

EQUATORIAL CURRENT OBSERVATIONS IN THE  
WESTERN INDIAN OCEAN IN 1975 AND 1976

Ants Leetmaa and Henry Stommel

Vertical profiles of current, temperature, and salinity were taken in the upper ocean from 3°S to 2°N along 55°30'E in the Indian Ocean during February-June in 1975 and 1976. During both years a strong O(80 cm/sec) equatorial undercurrent was present throughout the measurement period in the vicinity of the equator. A second region of eastward flow above the thermocline was observed at 3°S. During May and June the undercurrent moved southward and merged with the southern region of eastward flow. The meridional flow field was dominated by transients that during strong events were antisymmetric about the equator and had a vertical wavelength of about 180 meters. The transient events strongly affected the zonal flow field; during strong events the undercurrent was almost eliminated. This is in contrast to the GATE\* observations where the undercurrent was advected back and forth across the equator.

\*GARP Atlantic Tropical Experiment (GARP, Global Atmospheric Research Program)

Supported by: The Office of Climate Dynamics of the National Science Foundation.

DEEP EQUATORIAL JETS IN THE INDIAN AND PACIFIC OCEANS

James R. Luyten and Charles C. Eriksen

We report recent observations, from both the western Indian and central Pacific Oceans, of equatorially confined, energetic, multiple zonal jets of small vertical scale extending into the deep ocean. The basic similarity between the two sets of observations suggests that we have observed a general equatorial phenomenon. The observations in the Indian Ocean have demonstrated that the multiple jets have a time scale of the order of months, while the Pacific observations demonstrate that these jets extend coherently over some 11 degrees of longitude. Although it is tantalizing to speculate over the role that these jets may play in the heat and momentum balances of the equatorial oceans, these questions can only be answered by further exploration.

Supported by: ONR Contract N00014-76-C-0197, NR 083-400 and NSF Grants ATM76-02196 & OCE77-24822.

THE SUBTROPICAL RECIRCULATION OF SUBANTARCTIC MODE WATER

Michael S. McCartney

In the southern hemisphere, the dominant main pycnocline volumetric Mode Waters are subpolar in origin rather than subtropical as found in the northern hemisphere. Application of pycnostadal analysis techniques shows a basin-wide subtropical recirculation of these subantarctic Mode Waters in the South Pacific and Indian Oceans. Two techniques are used: (1) a core method-examination of the horizontal distribution of proportion at the depth of the most homogeneous water in the main pycnocline, and (2) an isopycnal method-examination of the horizontal distribution of vertical stability on density surfaces. The basin-wide extent of the recirculation of subantarctic Mode Water is in contrast to the westward concentrated recirculation of subtropical Mode Water in the North Atlantic and North Pacific Oceans.

Supported by: ONR Contracts N00014-74-C-0262, NR 083-004 & N00014-79-C-0071, NR 083-004 and NSF Grants OCE76-00390 & OCE77-22885.

ANOMALOUS WATER MASS DISTRIBUTIONS AT 55°W IN THE NORTH ATLANTIC IN 1977

Michael S. McCartney, L. Valentine Worthington and Mary E. Raymer

A hydrographic section made in July 1977 from the research vessel Knorr revealed a large-scale meridional distortion of the normal water mass distributions at 55°W in the North Atlantic. Cells of pure Labrador Sea Water were found within both the Gulf Stream and the westward recirculation of the gyre. A large cell of Mediterranean Water was found in the Slope Water, in contact with a cell of Subarctic Intermediate Water. Water at 11°C to 13°C within both the Gulf Stream and the Slope Water was anomalously saline. Throughout the Slope Water, Gulf Stream, and northern Sargasso Sea there was very little standard Western North Atlantic Water in the temperature ranges 3.4° to 9.0°C and 11° to 13°C. It is suggested that these meridional distortions are due in part to an increase in the amount of rotation of the horizontal velocity vector with depth during 1977 that was observed with current meters in the northern Sargasso Sea. An increase in the westward return flow strength may also have contributed. The ultimate cause of the anomalous property distributions and currents may be changes in the production rate and strength of the source waters for North Atlantic Deep Water and Western North Atlantic Water such as Labrador Sea Water, Mediterranean Water, and Eighteen Degree Water. The first and the last are known to have undergone convective formation events, in March 1976, and March 1977, respectively, in the period preceding the 1977 survey. The July 1977 section shows evidence of the recirculation of the new convectively formed Eighteen Degree Water.

In press: Journal of Marine Research.

Supported by: ONR Contracts N00014-74-C-0262, NR 083-004 & N00014-76-C-0197, NR 083-400 and NSF Grant OCE75-03962.

THE DISTRIBUTION OF DISSOLVED SILICATE IN THE DEEP WESTERN NORTH ATLANTIC OCEAN

Gerald J. Needell

The distribution of dissolved silicate in the deep western North Atlantic Ocean is presented. The potential temperature-dissolved silicate relationship is compared with the potential temperature-salinity relationship in the North Atlantic Deep Water. Geographical variations in the potential temperature-dissolved silicate relationship are discussed with particular emphasis on the low silicate

signal of the Western Boundary Undercurrent (WBUC). The WBUC is shown to have a significant influence on the potential temperature-dissolved silicate relationship from the Tail of the Grand Banks of Newfoundland to Cape Hatteras.

Supported by: NSF Grant OCE77-19403.

BENJAMIN FRANKLIN AND TIMOTHY FOLGER'S FIRST  
PRINTED CHART OF THE GULF STREAM

Philip L. Richardson

A print of the Franklin and Folger ca 1769-1770 chart, all copies of which have been 'lost' for nearly 200 years, was found in the Bibliothèque Nationale in Paris. This is the first chart of the Gulf Stream and continues today to be a good summary of its strength, course, and breadth.

In press: Science.

Supported by: US-France Exchange of Scientists Program (NSF & Centre National de la Recherche Scientifique) and ONR Contract N00014-74-C-0262, NR 083-004.

WEAKLY DEPTH-DEPENDENT  
SEGMENTS OF THE NORTH ATLANTIC CIRCULATION

William J. Schmitz, Jr.

Time-averaged horizontal currents obtained from long-term moored instruments deployed in the western North Atlantic over the Sohm Abyssal Plain along 55W exhibit two segments of weakly depth-dependent flow: one, near 36N, predominantly westward and narrow or jet-like (~200 km wide or less); the second primarily eastward, located near 37.5N, about 200-300 km south of the mean position of the axis of the Gulf Stream (its width cannot be estimated quantitatively with the data available because only one mooring with adequate vertical coverage is clearly located in this flow regime, but an upper bound of roughly 200 km seems plausible). In both cases, long-term mean zonal currents between 600 and 4000 m depths (nominal) vary in amplitude from only 6 to 10  $\text{cm s}^{-1}$  (approximately). The vertical structure of the westward recirculation flow regime varies with horizontal position, being both surface and bottom intensified as well.

The possibility exists that the identification of these weakly depth-dependent flow regimes may point to one way of increasing the transport of the Gulf Stream. That is, flow with weak vertical shear is added offshore of the more baroclinic segment of the Stream,

and possibly recirculated accordingly. This notion is generally consistent with all previous investigations which find the weakest vertical shears at the offshore edge of the Stream, wherever and however examined, and in particular with the addition of transport to the Florida Current over the Blake Plateau, after emerging from the Straits of Florida.

The horizontal patterns of the two weakly-depth dependent flow regimes found at 55W may be quite complex, containing variability on comparatively short and intermediate scales, associated to some extent with bottom topography. A specific example of the effect of bottom topography on the 55W data has been presented by Owens and Hogg. It is hypothesized herein that the observations described in the following may indicate the presence of a previously unknown, weakly depth-dependent smaller scale gyre recirculating within the subtropical gyre, with the former confined between the New England Seamounts and the Grand Banks of Newfoundland. It should be emphasized that other horizontal and vertical structures may be characteristic of different locations in the recirculation of the North Atlantic.

Eddy kinetic energy and the off-diagonal component of Reynolds' stress are also to some extent weakly depth-dependent in each of the weakly depth-dependent mean flow regimes noted above, relative to more mid-ocean locations. At one site in particular, the off-diagonal component of the Reynolds' stress is found to be essentially depth-independent.

The observation of weak depth-dependence in association with relatively strong abyssal currents for the recirculation regime could in principle help rationalize some of the difficulties in geostrophically balancing (at the leading order of approximation!), according to Worthington, the North Atlantic Circulation in this type of region. Estimates of contributions to momentum balances (based on the available moored instrument data) involving horizontal gradients of the Reynolds' stresses, or of the momentum transport by the time-averaged flow, are typically at least an order of magnitude less than the Coriolis force associated with the zonal (or downstream) mean flow component, and possibly also the meridional (or cross-stream) flow component at most locations, thereby precluding violation of geostrophy at leading order by these effects. Geostrophic terms associated with estimates of the curvature of the Reynolds' stresses and/or mean momentum flux could be significant at the next order of approximation in the immediate vicinity of the Gulf Stream or near topographic features. Niiler has developed a model of an eddy-driven mean flow, where the eddy-terms in the vorticity

equation are locally significant only in the Gulf Stream, but with a basin-wide mid-ocean flow driven in response to the non-compensated eddy-induced pressure gradient at the offshore edge of the region where eddy effects are locally significant dynamically. Two recent hydrographic sections across the Gulf Stream and recirculation along 55W were found to be in mass balance geostrophically, relative to the bottom.

In press: Journal of Marine Research.

Supported by: ONR Contract N00014-76-C-0197, NR 083-400 and NSF Grant OCE75-03962.

#### OCEANIC WARMING OF WESTERN EUROPE

Henry M. Stommel

In the northern North Atlantic off Europe, deep convection flushes buoyancy and heat out of the upper ocean each winter. It is replaced by horizontal advection during the remainder of the year. Absolute geostrophic currents can be computed from an application of the heat conservation equation. A remarkable spiral with depth emerges as a key feature in the process. The computed field of flow appears to be consistent with several buoyancy and heat flux requirements, with the independent physical information of locally vanishing curl of the wind-stress, and with its implications through the Sverdrup relation.

Published in: Proceedings of the National Academy of Sciences, USA 76: 2518-2521, 1979.

Supported by: NSF Grant OCE78-18460.

#### T H E O R E T I C A L M O D E L S

##### A DEVELOPING TURBULENT SURFACE SHEAR LAYER MODEL

Gabriel T. Csanady

The development of a surface shear layer, following the sudden application of wind stress, is governed by a steady increase in total momentum and a downward penetration of the shear flow region. Analogy with the turbulent boundary layer suggests a two-layer conceptual model with an interface layer at the surface and an outer layer below. The growth of the outer layer may be supposed to be described by an entrainment law and an eddy viscosity proportional to local length and velocity scales. Matching to an interface layer yields a surface velocity increasing only very slowly with time and having a typi-

cal magnitude of  $30u_*$ . A comparison with constant viscosity and space dependent viscosity models shows that a unique feature of the developing shear layer model is the vertical penetration of a shear impulse, followed by low shear in the developed region of the flow. Some scant experimental data seem to support this model, but systematic experimental work on the problem is yet to be carried out.

Published in: Journal of Geophysical Research 84: 4944-4948, 1979.

Supported by: The Techniques Development Laboratory of the National Weather Service, NOAA.

#### THE EVOLUTION OF A TURBULENT EKMAN LAYER

Gabriel T. Csanady and Ping Tung Shaw

The evolution of shear flow at the sea surface, following the sudden application of wind stress, is modelled as a wall layer -- outer layer combination of turbulent flow. The outer layer eddy viscosity is proportional to eddy length scale and hence to the penetration of the shear flow, so that it grows initially, then approaches a constant asymptote. The analytical solution for time-dependent eddy viscosity has a structure very similar to the classical Ekman-Fredholm solution for constant viscosity. In physical terms, the spontaneous depth limitation of the shear layer at the surface of a rotating viscous fluid remains effective in turbulent flow even though the viscosity is not constant in space or time.

When a sharp density interface limits the downward penetration of a surface shear layer at a "mixed" layer depth  $h$ , the same rotating-viscous fluid effect controls the shear across the interface, and hence the entrainment rate. Therefore the equilibrium depth of a mixed layer remains proportional to  $u_* / f$ , as the depth of the shear layer in a homogeneous fluid ( $u_* =$  friction velocity,  $f =$  Coriolis parameter). A detailed model of the equilibrium mixed layer may be constructed by a combination of a free surface wall layer, an outer layer, and an interface wall layer. The behavior of this model is similar overall to the classical model of Rossby and Montgomery (Pap. Phys. Oceanogr. Meteorol. 3(3), 101 pp, 1935) and leads to bulk formulae of identical structure.

Supported by: The Techniques Development Laboratory of NOAA and the Department of Energy.

DENSITY-DIFFUSIVE MODEL OF THE NINETYEAST  
RIDGE CURRENT

Eric S. Johnson and Bruce A. Warren

A model for the structure of deep western boundary currents, based on linear momentum equations and lateral mixing of density, is applied to data from a recent section across the Ninetyeast Ridge current in the eastern basin of the Indian Ocean. It accounts moderately well for the breadth of the current, as inferred from the density distribution, and for the form of its velocity profile, as inferred (roughly) from the silica distribution.

Published in: *Journal of Physical Oceanography* 9: 1288-1293, 1979.

Supported by: W.H.O.I. Summer Student Fellowship and ONR Contract N00014-74-C-0262, NR 083-004.

ON THE PROPAGATION OF FREE TOPOGRAPHIC  
ROSSBY WAVES NEAR CONTINENTAL MARGINS  
PART 1: ANALYTICAL MODEL FOR A WEDGE

Hsien Wang Ou

An analytical model has been constructed to study the propagation of free waves of sub-inertial frequency in an infinite wedge filled with a uniformly stratified fluid. The problem is found to be transformed into the corresponding surface gravity wave problem in a nonrotating homogeneous fluid with the roles of the surface and bottom boundaries interchanged. Analytical solutions are thus available for waves that are either progressive or trapped in the cross-wedge direction, forming respectively continuous and discrete spectra in frequency space. The separation occurs when the nondimensional wave frequency  $\sigma$  (scaled by the inertial frequency  $f$ ) equals the Burger number  $S$ , defined here as  $(N/f)\tan\theta^*$ , where  $N$  is the Brunt-Väisälä frequency, and  $\tan\theta^*$  is the bottom slope. Since an infinite wedge has no intrinsic length scale, the only relevant nondimensional parameters are the wave frequency  $\sigma$  and the Burger number  $S$ . Thus, stratification and bottom slope play the same dynamical role, and the analysis is greatly simplified. Asymptotic solutions for the progressive waves have been obtained for both the far field and small  $S$ . The former enables us to study in detail some basic wave properties in the far field, and the latter enables us to examine the spatial evolution of the wave amplitude and phase as these waves approach the apex when  $S$  is small. The general solution is then presented and discussed in some detail. The eigenfrequencies of the trapped modes decrease when  $S$  decreases and reduce to the short wave limit of Reid's re-

sult for his second class, barotropic edge waves when  $S$  approaches zero. The modal structure broadens as  $S$  increases to some critical value above which no such coastally-trapped modes exist.

Supported by: NSF Grants OCE76-01813 & OCE78-19513.

ON THE PROPAGATION OF FREE TOPOGRAPHIC  
ROSSBY WAVES NEAR CONTINENTAL MARGINS  
PART 2: NUMERICAL MODEL

Hsien Wang Ou and Robert C. Beardsley

Ou has presented in Part 1 an analytical model for the propagation of free topographic Rossby waves in a semi-infinite wedge. We present here in Part 2 a numerical model incorporating more realistic topography and bottom friction to simulate the low frequency dynamical processes occurring near continental margins. The numerical model also includes density stratification, and the model results suggest that the maximum energy flux transmission coefficient obtained in the barotropic model by Kroll and Niiler (J. Phys. Oceanogr. 6: 432-450, 1976) is an upper bound. Baroclinic fringe waves are generated near the slope/rise junction, and in the presence of a finite slope change, they may cause an amphidromic point to form at some mid-depth level and locally reverse the direction of phase propagation above it. These baroclinic fringe waves also cause an offshore heat flux over the continental rise which is in distinct contrast to the onshore heat flux generated over the slope region in a frictionless model. In the cross-shore direction, the mean heat and mass balance implies a mean Eulerian circulation of two counter-rotating gyres with downwelling occurring near the slope/rise junction. Bottom friction generates an offshore heat flux near the bottom and therefore modifies the mean flow pattern over the slope region. The induced alongshore mean flow is approximately geostrophic and points to the left facing the shoreline except near where the baroclinic fringe waves dominate. The mean thermal wind relation implies a generally denser slope water than that farther offshore.

We have compared some of the model predictions with current and temperature data obtained south of New England during 1976. The comparisons are generally consistent, suggesting that topographic Rossby wave dynamics play an important role for the low frequency motions over the continental rise and slope.

Supported by: NSF Grants OCE76-01813 & OCE78-19513.

A THEORY OF THE MEAN FLOW DRIVEN BY LONG  
INTERNAL WAVES IN A ROTATING BASIN,  
WITH APPLICATION TO LAKE KINNERET

Hsien Wang Ou and John R. Bennett

The rectified flow induced by wind-driven internal seiches in a rotating lake is studied. Friction and nonlinearity combine to generate a secondary mean flow which is calculated analytically for the case of a uniform depth lake and numerically for variable depth. The theory is applied to Lake Kinneret, the former Sea of Galilee, where the diurnal wind forcing produces a large internal Kelvin wave and which has a strong cyclonic mean flow. The uniform depth model reproduces the diurnal response adequately, but variable depth is required to reproduce the mean flow.

Published in: Journal of Physical Oceanography 9: 1112-1125, 1979.

Supported by: Brookhaven National Laboratory Contract 357213-S, Great Lakes Environmental Research Laboratory, NOAA, Contract 03-022-57, and NSF Grant OCE76-01813.

FLOAT TRAJECTORIES IN SIMPLE  
KINEMATIC FLOWS

Lloyd Regier and Henry Stommel

A simple kinematic model has been used to compute Lagrangian trajectories. Although it is certainly too simple to model geophysical flows, it has provided insights into the behavior of Lagrangian tracers. In particular, the existence of trapping regions has been shown to greatly increase the dispersion rate of tracers and to lead to net tracer displacements when the Eulerian mean flow is zero. In general, the spectrum of spatial scales present in the trajectories is wider than the Eulerian spectrum and is biased towards shorter wavelengths; the disparity between the 100-km Eulerian scale and the much shorter length scales experienced by the tracers is demonstrated. The estimation of the Eulerian parameters of the field from Lagrangian observations must be done with a great deal of care, particularly if the eddy flow velocities are comparable to or exceed the mean flow. With a limited number of tracers it is extremely difficult to estimate, with any

degree of confidence, the properties of either the mean Eulerian flow or the eddy field. Clearly, more effort must be spent to better understand the behavior of tracers in more realistic flows, to devise data analysis techniques, and to relate the Eulerian and Lagrangian spectra.

Published in: Proceedings of the National Academy of Sciences, USA 76, 4760-4764, 1979.

Supported by: NSF Grant OCE77-15600.

L A B O R A T O R Y M O D E L S

SELECTIVE WITHDRAWAL  
OF ROTATING STRATIFIED FLUID

John A. Whitehead, Jr.

A simple theory backed by some experimental observations is presented of the transient withdrawal of rotating, stratified fluid in a field of gravity. The problem is confined to the case where the geometry is axisymmetric and viscosity is negligible. It is predicted that the withdrawal initially proceeds like nonrotating selective withdrawal, but at a time equal to  $3\sqrt{3}/2f$  there is a transition to a rotation-dominated selective withdrawal process which requires that fluid come from distances above and/or below the inlet given by the time-dependent formula  $(fQt/2\pi r_0 N)^{1/2}$ . Experimental observations are given which are in approximate agreement with the predictions.

Supported by: NSF Grant OCE78-09448.

LABORATORY SIMULATION OF THE GYRE  
IN THE ALBORAN SEA

John A. Whitehead, Jr. and Arthur R. Miller

A laboratory experiment is described which appears to exhibit flows which are similar to the flow-counterflow in the Strait of Gibraltar and, for certain values of the parameters involved, to the gyre and front in the western Alboran Sea. The experiment is transient in nature and is made with two connecting basins on a rotating turntable. A sliding door is fitted into the channel connecting the two

basins. Each basin is filled with water, the door is closed, and salt is added to one side so that the two waters have different densities. After the waters have spun up to rest in the rotating frame, the door is opened. A flow, driven by the density imbalance, is observed shortly thereafter, the lighter fluid rising up over the heavier fluid and pushing into the basin containing the heavy fluid. Likewise the heavy fluid pushes into the basin containing lighter fluid. For very rapid rotation these flows are violently unstable. For less rapid counterclockwise rotation both currents stay confined to a narrow jet which clings to the right-hand wall of the basins which they are entering. At some lower rate of rotation the jet cannot hold to a sufficiently curved wall, and the jet separates from the wall-- a gyre is observed between the jet and the wall. The gyre and the jet initially are both a Rossby radius in size, but gradually the gyre grows larger. Growth of the gyre seems to result from an accumulation of fluid from the jet as it returns to the wall. Scaling arguments and estimates of buoyancy, Coriolis, and wind forces are advanced in support of the concept that this laboratory-produced gyre and the gyre in the Alboran Sea share the same dynamics.

Published in: Journal of Geophysical Research 84: 3733-3742, 1979.

Supported by: NOAA Grant no. 04-8-M01-117 & Dept. of State, Treaty of Friendship and Cooperation between Spain & U.S.

## RINGS, EDDIES

### AVAILABLE POTENTIAL ENERGY FOR MODE EDDIES

Nancy A. Bray and Nicholas P. Fofonoff

A technique for estimating available potential energy (APE) for mesoscale eddies in the ocean is developed by introducing a reference density field that is a function of pressure only and that is connected to the observed field by adiabatic vertical displacements. The full empirical equation of state is used in the computational algorithm. The accuracy of the estimate is limited by the data and sampling and not the algorithm itself, which can be made as precise as desired.

The reference density field defined locally for an ocean region allows redefinition of dynamic height  $\Delta D$  (potential energy per unit mass) relative to the reference field. APE per unit area becomes simply the horizontal average of dynamic height integrated over depth in the region considered.

The procedure is applied to the MODE density data collected in 1973. For each group of stations within five two-week time windows (designated Groups A to E) the estimated APE was found to be comparable to the low-frequency kinetic energy measured from moored buoys. Changes of potential energy associated with changes of the reference field from one Group to another are several times as large as the APE within each window, indicating that processes of scales larger than the station grid are more energetic than those associated with the horizontal differences of density within the grid.

Supported by: ONR Contract N00014-76-C-0197, NR 083-400.

### EDDIES OFF THE SOMALI COAST DURING THE SOUTHWEST MONSOON

John G. Bruce

The development and decay of the large eddy in the northern Somali Basin and its smaller associated eddies each southwest monsoon in the northwestern Indian Ocean has been monitored for four consecutive years by a time series of temperature sections obtained along the tanker sea lane across the Somali Basin. The evidence suggests that the large eddy first forms between 4°N to 12°N during late May and tends to remain approximately in this location throughout the entire southwest monsoon.

In press: Journal of Geophysical Research.

Supported by: ONR Contract N00014-74-C-0262, NR 083-004.

### SOMALI EDDY FORMATION DURING THE COMMENCEMENT OF THE SOUTHWEST MONSOON, 1978

John G. Bruce, D. Rudolf Quadfasel and John C. Swallow

An early stage of the Somali eddy circulation was mapped in the period 29 May - 13 June, 1978 using expendable bathythermograph data at closely spaced stations. By this time the southwest monsoon had been blowing at 5°N for about 4 weeks and the large anticyclonic eddy in the northern Somali Basin was clearly discernible between 3°N and 10°N. It is estimated that the offshore transport at this time was approximately half of that occurring during the period when the eddy reaches maximum size and strength during August and September. A smaller southern eddy was observed just offshore between the equator and 3°N.

Supported by: ONR Contracts N00014-74-C-0262, NR 083-004 & N00014-79-C-0071, NR 083-004.

ANTICYCLONIC EDDIES GENERATED NEAR  
THE CORNER RISE SEAMOUNTS

Philip L. Richardson

During 1977 two freely drifting buoys, originally in the Gulf Stream, looped over and in the lee of the Corner Rise seamounts. The trajectories suggest that by mid-August an anticyclonic eddy was generated over the seamounts, where it remained for six weeks. During the period October-December it left the seamounts and drifted southwestward with a mean speed of 5 cm/sec. The eddy was characterized by a clockwise circulation with speeds of 30 cm/sec and an overall size of 200 km. An expendable bathythermograph survey showed that the eddy contained a warm core manifested by a depression of the main thermocline; at the center the 15° isotherm was located at a depth of 715 m. During the period June-August a third buoy looped in a second anticyclonic eddy which also drifted southwestward in the lee of the Corner Rise. The implication of these measurements is that, every few months, warm core eddies form near the Corner Rise and that they subsequently drift southwestward forming a wake region downstream of the seamounts.

Supported by: NSF Grant OCE77-08045, ONR Contract N00014-74-C-0262, NR 083-004 and US-France Exchange of Scientists (NSF & Centre National de la Recherche Scientifique).

GULF STREAM RING TRAJECTORIES

Philip L. Richardson

During the period 1976 to 1978, the movement of fourteen Gulf Stream rings, including two anticyclonic and twelve cyclonic rings, was measured with satellite-tracked free-drifting buoys. The buoys in the cyclonic rings showed a tendency to move out toward the high velocity region of the ring and to remain there circling the center. One buoy stayed in a ring as long as eight months and completed 86 loops. Periods of rotation ranged from less than two days up to ten days. The movement of the rings was complicated and appears to be related to the Gulf Stream and strong topographic features such as the New England Seamounts. Rings that were not touching the Stream generally moved westward with typical speeds of 5 cm/sec. Rings that were attached to the Stream generally moved downstream in the Stream with speeds up to 75 cm/sec. Frequently rings coalesced with the Gulf Stream and one of the following three things seemed to happen: (1) the ring turned into an open meander of the Stream and was lost; (2) the ring was advected

rapidly downstream in the Stream and was presumably lost; (3) the ring became attached to the Gulf Stream and then split off again as a modified ring.

In press: J. Physical Oceanography.

Supported by: NSF Grants OCE75-08765 & OCE76-82059, ONR Contract N00014-74-C-0262, NR 083-004, and US-France Exchange of Scientists Program (NSF & Centre National de la Recherche Scientifique).

THE PHYSICAL STRUCTURE AND LIFE HISTORY OF  
CYCLONIC GULF STREAM RING ALLEN

Philip L. Richardson,  
Catherine J. Maillard and Thomas B. Sanford

A cyclonic Gulf Stream ring, Allen, was followed over its life, from September 1976 to April 1977 in the region north of Bermuda. Conductivity-temperature-depth, expendable-bathythermograph, and velocity profile measurements were made in Allen, and, over the last five months of its life, satellite buoys were used to continuously track its movement. The measurements indicate that in December 1976 Allen split into two rings, a large one, Allen, and a small one, Arthur. Arthur moved rapidly eastward and coalesced with the Gulf Stream near the New England Seamounts. Allen moved in a large clockwise loop; at the end of February 1977 it became attached to the Gulf Stream and reformed into a modified ring, smaller in size and faster in rotation. At the end of April 1977, the modified ring coalesced with the Gulf Stream and disappeared as it was advected downstream in the Stream. The principal results of this study are that:

- 1) The New England Seamount chain was a major influence in the genesis of Allen and on the trajectories of nearby rings.
- 2) While a free eddy, months after its formation, Allen evolved into a bimodal or peanut-shaped structure.
- 3) The bimodal structure ultimately bifurcated, spawning a new isolated eddy, denoted as Arthur, and a modified remnant, Allen.
- 4) The velocity field of Allen involved the whole water column, with bottom velocities of 10-15 cm sec<sup>-1</sup>.
- 5) The barotropic velocity at the center of Allen (6 cm sec<sup>-1</sup> to NNW) was about equal to its translation velocity (4 cm sec<sup>-1</sup> to NW).
- 6) Especially energetic inertial motions were seen at the center of Allen; these may play a role in enhancing the stirring of water properties.
- 7) Allen survived several close encounters or entrainments with the Gulf Stream, proving that such encounters can be non-fatal to a ring.

8) The encounters appear to result in injections (exchanges) of water (momentum, heat, etc.) into the rings at an estimated rate of  $10^6 \text{ m}^3 \text{ sec}^{-1}$  per ring.

9) The behavior of Allen and Arthur was in contrast to the results of some other studies which have shown that rings generally drift slowly and passively southwestward.

In press: Journal of Geophysical Research.

Supported by: ONR Contract N00014-74-C-0262, NR 083-004 and NSF Grants DES74-02783, OCE76-82059 & OCE76-24605.

OBSERVED AND NUMERICALLY SIMULATED KINETIC ENERGIES FOR MODE EDDIES

William J. Schmitz, Jr. and W. Brechner Owens

It is demonstrated that the outcome of an intercomparison between data and the vertical distribution of eddy kinetic energy predicted by a previously developed numerical model of the MODE area is frequency dependent. In the range of periods from 50 to 150 or even to 400 days (one definition of the temporal mesoscale, the scale that the model was designed to simulate), the comparison is quite good. For periods in the range of 5 to 50 days, the agreement is poor. For periods longer than 400 days, the comparison is indeterminate. Earlier conclusions concerning the relation of model results to the MODE data should be qualified by stipulating frequency range, and future intercomparisons for any model in all regions should be conscious of the desirability of doing so across common frequencies.

Published in: Journal of Physical Oceanography 9: 1294-1297, 1979.

Supported by: ONR Contract N00014-76-C-0197, NR 083-400 and NSF Grant OCE75-03692.

TURBULENCE AND MIXING, TOPOGRAPHIC EFFECTS

ANOMALOUS WATER IN THE DEEP OCEAN SUGGESTS LATERAL ADVECTION/STIRRING

Laurence D. Armi

Although Amos and Gerard (Science 203: 894, 1979) report that anomalous bottom water south of the Grand Banks suggests turbidity current activity, their temperature and density data are incorrectly interpreted. The anomalous water found cannot be the result of downslope advection during a turbidity cur-

rent event as advocated but is more likely due to resuspension by high mesoscale currents. Similar water has already been identified at many stations throughout the western North Atlantic.

In press: Science.

Supported by: NSF Grant OCE76-81190 and ONR Contract N00014-76-C-0197, NR 083-400.

FLOW STRUCTURES OF THE BENTHIC OCEAN

Laurence Armi and Eric D'Asaro

Three dimensional structure of the near bottom density field was observed with a towed yo-yoing profiler and a fixed current/temperature measuring array on the Hatteras Abyssal Plain. A great variety of structures were seen. Immediately above the bottom a well mixed bottom layer extends vertically 5 to 60 m, with less than  $1 \text{ m}^\circ\text{C}$  potential temperature change. This mixed layer is often capped by a region of strong vertical potential temperature gradient, with up to  $100 \text{ m}^\circ\text{C}$  potential temperature change in  $\sim 10 \text{ m}$ . The boundary layer may be uniform for 10 km, or exhibit a bottom temperature gradient of up to  $20 \text{ m}^\circ\text{C}$  per kilometer. Interior layers of nearly constant potential temperature and horizontal extent of 2 to 100 km are seen  $\sim 25\%$  of the time above the bottom mixed layer. When an interior layer is present, the bottom mixed layer is thinner. On many occasions an interior layer was seen to be continuous horizontally with the bottom mixed layer, suggesting formation of interior layers by detachment of the bottom mixed layer. A benthic front was observed. Differential horizontal advection is required to explain the observed structures. Velocity fluctuations above 1 cph increase in energy near the bottom, presumably a signature of turbulence in the mixed layer; these fluctuations are modulated by the passage of structures observed in the moored record.

In press: Journal of Geophysical Research.

Supported by: ONR Contract N00014-76-C-0197, NR 083-400, NSF Grant OCE76-81190 and NSF Graduate Fellowship.

SIGNATURES OF MIXING FROM THE BERMUDA SLOPE, THE SARGASSO SEA AND THE GULF STREAM

Michael C. Gregg and Thomas B. Sanford

Measurements of temperature microstructure and velocity shear were made from nearly simultaneous profiles taken immediately adjacent to

the island of Bermuda. Profiles with intense microstructure were found in regions with pronounced step-like finestructure containing nearly adiabatic regions from 2 to 10 m thick. These were the locations in which large scale surveys found that eddies impinging on the island were forcing alongshore flow. However, no significant correlation was found between 10 m shear values and the microstructure levels.

A limited number of profiles were also taken in the Sargasso Sea and in the Gulf Stream. A 150 m deep turbulent mixed layer was found in the Sargasso Sea during a period of light winds and possible surface cooling. A mean shear of  $0.01 \text{ s}^{-1}$  across a 100 m thick section at the base of the layer may also have been responsible for driving the turbulence in the layer. The microstructure levels below the mixed layer were consistent with those from the more active of three cruises to the central Pacific.

The microstructure activity in the Gulf Stream was dominated by double diffusivity signatures on the upper and lower boundaries of numerous temperature inversions of intrusive origin. The high shear values did not inhibit the diffusive steps on the inversions nor the formation of thicker layers beneath the inversions. In sections not containing inversions, the Cox numbers were little different from those in the Sargasso Sea. Thus, in terms of small scale mixing, the Gulf Stream resembles other boundaries between different water masses, such as the California Current, more closely than it does the Equatorial Undercurrent, which has regions of intense overturning activity.

In press: J. Physical Oceanography.

Supported by: ONR Contract N00014-74-C-0262, NR 083-004.

SOME BOTTOM TOPOGRAPHY PROBLEMS IN  
PHYSICAL OCEANOGRAPHY

Nelson G. Hogg

The theoretical literature concerning steady flow of a rotating fluid past obstacles is reviewed with emphasis on effects of stratification and problems with potential pertinence to oceanography. The central dynamical property of these flows is the conservation of potential vorticity and the consequent production of relative vorticity through compressing or stretching vortex lines at the bottom boundary. Obstacles are broadly classified as seamounts, islands and ridges, and within the last group channel flow is also considered.

Small amplitude topography can produce  $O(1)$  relative vorticity -- the key parameter being the ratio of the fractional change in water depth to the Rossby number. If this parameter is greater than some number of  $O(1)$ , enough relative vorticity can be produced to cause closed streamlines over the obstacle, at least in problems where cross stream variations are allowed (e.g., seamounts, channel flows). This closed streamline pattern decays with height at a rate which depends on the stratification and can be considered a generalized Taylor column. Inclusion of the  $\beta$ -effect, upstream shear, a bottom slope or channel walls permits stationary, lee-wave production. Finite amplitude topography and free surface effects are also reviewed.

Available oceanographic observations supporting the theoretical results are presented. Although there is little work done on a scale small enough to resolve topographic effects, there is a growing body of observational material that qualitatively supports the physical basis for the studies.

In press: GARP Publication Series.

Supported by: ONR Contract N00014-76-C-0197, NR 083-400 and NSF Grant OCE78-25405.

DYNAMICAL INTERPRETATION OF LOW FREQUENCY  
MOTIONS NEAR VERY ROUGH TOPOGRAPHY --  
THE CHARLIE GIBBS FRACTURE ZONE

Nelson G. Hogg and William J. Schmitz, Jr.

Moored observations of current, nine months in duration, at two sites 10 km apart on the north wall of Charlie Gibbs Fracture Zone show large, frequency dependent, spatial variations. A brief description related to the general circulation of the area was given by Schmitz and Hogg (J. Mar. Res. 36: 725-734, 1978); here we rationalize the observations with quasigeostrophic wave theory and various simplified models of the topography. Detailed bathymetry shows that large amplitude corrugations are superimposed on the general slope of the north wall and trend northward with peak to peak amplitude 600 m and east-west wavelength 18 km. A potential vorticity model suggests that the effect of these corrugations is sufficiently strong so that isobars are almost coincident with isobaths and the differences in observed mean flow are related to differences in the local separation of isobaths. The very longest period motions decrease in energy toward the bottom whereas higher frequencies are bottom intensified, the degree of intensification and ratio of upslope to longslope velocity increasing with

frequency. Energy decreases markedly moving upslope at the lowest frequencies. The computation of empirical orthogonal functions reveals three frequency bands within which the characteristics of motion change slowly. At the lowest band (periods 19-96 days) the dominant mode is weakly bottom intensified and mostly east-west while a second mode decreases toward the bottom with approximate energy equipartition. Only one mode is distinguished at intermediate frequencies (3.6-19 days) and it is bottom intensified. Beyond 3.6 days two modes exist, the most energetic being highly bottom trapped. Low frequency wave theory is explored for four models of the north wall. For a discrete sloping step the reflection properties are such that cross-slope modes are established and these are matched at slope changes by horizontally trapped baroclinic fringe waves. Adding corrugations to the step leads to the possibility of waves existing above their normal cut off frequency because of the enhanced roughness. These resemble smooth step topographic waves with a strongly trapped near bottom perturbation. The combination of these effects gives a reasonable explanation for the character of the observed motions.

Supported by: ONR Contract N00014-76-C-0197, NR 083-400.

OCEANIC OBSERVATIONS OF STRATIFIED TAYLOR  
COLUMNS NEAR A BUMP

W. Brechner Owens and Nelson G. Hogg

Analysis of hydrographic and moored instrument records show that the flow over a 400 m high seamount, centered at 55°W, 36°N in the recirculation region of the Gulf Stream system, resembles a stratified Taylor column. Potential density sections indicate a bottom intensified flow over the seamount with a vertical scale of approximately 3 km. Time series of relative vorticity deduced from the current meter records show a significant (anti-) correlation with the bathymetry and a similar vertical scale as seen in the density structure. Estimates of the vorticity balance 1000 m above the bottom demonstrate that the balance is between the advection of relative vorticity and vertical vortex stretching which is consistent with Taylor column behavior. These results suggest that the bathymetry distorts the larger scale mean circulation so as to produce large amplitude, small scale variability which should be taken into account before one extrapolates isolated moored measurements.

In press: Deep-Sea Research.

Supported by: NSF Grants OCE75-03962 & OCE77-19403 and ONR Contract N00014-76-C-0197, NR 083-400.

DETERMINATION OF WATER MASS PROPERTIES OF  
WATER PUMPED DOWN FROM THE EKMAN LAYER  
TO THE GEOSTROPHIC FLOW BELOW

Henry M. Stommel

In a subtropical gyre, the convergent Ekman layer forces water downward into the geostrophic flow below. The properties and depth of the mixed layer vary considerably during the course of the year, but this variability does not penetrate into the geostrophic region. Evidently there is some process at work that selects only late winter water for actual net downward pumping. It is a process much like that performed by Maxwell's Demon. Arguing from a particular example in a North Atlantic region where Sverdrup dynamics is presumed to prevail, an elementary description is given as to how the Demon works and a sample set of profiles by season is computed. Present day mixed layer models involve a local vertical mixing process. Thermocline theories involve adiabatic flow from high latitudes. There is an intermediate depth range at which the two processes operate alternatively, according to season.

Published in: Proceedings of the National Academy of Sciences, USA 76: 3051-3055, 1979.

Supported by: NSF Grant OCE78-18460.

I N T E R N A L   W A V E S

INTERNAL WAVES, FINESTRUCTURE, MICROSTRUCTURE,  
AND MIXING IN THE OCEAN

Michael C. Gregg and Melbourne G. Briscoe

Progress in measuring, interpreting, and understanding oceanic internal gravity waves and fine and microstructure is reviewed; we emphasize the quadrennium 1975-1978. The context is how these subjects contribute to oceanic mixing. The overlap between the areas is examined, as is the relevance of the subjects to other aspects of oceanography.

Present trends and suggestions for future work are included, and we offer some speculation on possible progress during the next quadrennium, which may be substantial especially for finestructure understanding.

Published in: Reviews of Geophysics and Space Physics, 17: 1524-1548, 1979.

Supported by: ONR Contracts N00014-75-C-0502 & N00014-76-C-0197, NR 083-400 and NSF Grant OCE77-25803.

ANOMALOUS BEHAVIOR OF INTERNAL GRAVITY WAVES NEAR BERMUDA

Charles L. Johnson and Thomas B. Sanford

Observations of vertical profiles of horizontal velocity made around the island of Bermuda during the Fine and Microstructure Experiment (FAME) reveal anomalies in the internal wave field associated with the island bathymetry. Compared to similar data taken at open ocean sites, the near-Bermuda data exhibit lower horizontal kinetic energy levels. Also, whereas the open ocean data consistently show the dominance of clockwise over anticlockwise polarized (with depth) energy, implying a near surface energy source, the Bermuda profiles frequently consist of mostly anticlockwise polarized energy. The internal wave field possesses a significant in-shore over along-shore shear anisotropy, which, together with the anticlockwise polarization, might signify a bottom energy generation with subsequent propagation radially away from the island. High levels of temperature finestructure [measured with a conductivity-temperature-depth sensor (CTD)] and large shear anisotropies are related to both strong vertical shears and proximity to the island. The relation to the strong shear is believed to be a result of the effect of horizontal internal wave displacements on the time-mean horizontal temperature gradient. No relation between the degree of shear anisotropy and the energy level of the waves is found.

Supported by: ONR Contracts N00014-74-C-0262, NR 083-004 & N00014-79-C-0071, NR 083-004.

BISPECTRA OF INTERNAL WAVES

C. Henry McComas and Melbourne G. Briscoe

This note summarizes a detailed numerical computation of bispectra arising from weak nonlinear resonant interactions of internal waves whose energies are represented by the Garrett & Munk model spectrum. Two spectra are computed--the bispectrum of power and the auto-bispectrum of vertical displacement. These are chosen because the first is the most informative and the second is easy to observe. The numerical computations indicate that the level of the bispectral signal is much too low to be detected by any reasonable observational programme. Even more disturbing, bispectra of

Eulerian variables are subject to a kinematic contamination causing a significant bispectral level which can easily be misinterpreted as a nonlinear interaction.

In press: Journal of Fluid Mechanics.

Supported by: NSF Grants OCE76-23532, OCE76-14739 and OCE77-25803.

CRITICAL LAYERS AND THE GARRETT-MUNK SPECTRUM

Barry R. Ruddick

The effects of critical level absorption of oceanic internal waves by a mean flow are estimated using the Garrett and Munk (J. Geophys. Res. 80: 291-297, 1975) model spectrum. The horizontal currents of the wave field are found to be more intense perpendicular to the mean flow than parallel to it. However, the current anisotropy is only half as large as would be necessary to explain Frankignoul's (J. Phys. Oceanogr. 4: 625-634, 1974) observations. The wave momentum flux absorbed by the mean flow corresponds, for a 400 m thick shear zone, to a wave-induced vertical eddy viscosity of about  $-100 \text{ cm}^2 \text{ s}^{-1}$ . The effect of the absorbed momentum on the mean flow is to cause a slow (2.5 m/day) downward motion, and slow spreading, of the shear profile.

Supported by: ONR Contract N00014-76-C-0197, NR 083-400.

SURFACE LAYER PROCESSES AND METEOROLOGY

IMPORTANCE OF EDDY HEAT FLUX IN A HEAT BUDGET FOR OREGON COASTAL WATERS

Harry L. Bryden, David Halpern and R. Dale Pillsbury

A heat budget for Oregon coastal waters during the summer upwelling season in 1973 is estimated from current and temperature measurements at a distance of 15 km from the Oregon coast. In this heat budget, the time averaged onshore-offshore circulation transports heat offshore at an estimated rate of  $4.5 \times 10^4 \text{ cal cm}^{-1} \text{ s}^{-1}$ . This offshore heat transport is compensated by a combination of onshore eddy heat flux, alongshore variation of alongshore heat transport, radiative heat gain by coastal waters, and cooling of coastal waters during summer. Of these mechanisms, the eddy heat flux is most important, balancing 40% of the offshore heat transport by the mean circulation. The eddy heat flux is di-

rected down the mean horizontal temperature gradient and thus removes potential energy from the mean circulation. Removal of energy by eddies is estimated to be 80% of the energy put into the water column by the mean wind stress acting on the mean surface current. By removing energy from the mean circulation, eddies provide a mechanism limiting the magnitude of the alongshore circulation in Oregon coastal waters.

Supported by: NSF/IDOE Agreement AG-299 and NSF Grants GX 33502, GX 28746 & OCE77-22887.

TRENDS OF VARIABLES AND ENERGY FLUXES OVER THE ATLANTIC OCEAN FROM 1948 TO 1972

Andrew F. Bunker

Regression coefficients have been computed from monthly, seasonal, and annual means of 11 meteorological variables and 8 energy fluxes by 10-degree areas over the North and South Atlantic Oceans from January 1948 through December 1972. Many linear trends of annual means have been plotted on charts and studied for spatial and flux-variable relationships. Pressure tendencies showed that pressures increased under the eastern part of the subtropical high-pressure cells in both hemispheres and decreased east of the mean trough extending southwestward from the Icelandic low-pressure center. Net effects of these trends were to increase the strengths of the westerlies and easterlies in both hemispheres. Meridional winds evolved in such a manner that warm air transport to Greenland increased. Equatorward wind components increased over the eastern tropical Atlantic. Charts presenting trends in air temperature, humidity, clouds, rain and surface fluxes show the relations between these variables, surface fluxes, changing circulation patterns and sea surface temperature. The mixing ratio trend is negative over both oceans with maximum decrease over the Gulf of Mexico and the east coast of North America. A general decrease in sea temperature is noted over all of the North Atlantic with large decreases off New England and the Maritime Provinces. Long-term sea temperature averages compiled by others indicate that the North Atlantic decrease can be considered as a return to more normal temperatures after two decades with abnormally high temperatures. Upward sea temperature trends are noted in the trade wind region of the South Atlantic. Latent heat flux trends usually determine the trend of the heat gain by the ocean. When latent heat flux trends result from oceanographic

changes, i.e., advection or upwelling changes, inverse relations between sea surface temperature and heat gain by the ocean occur. When meteorological changes such as circulation patterns cause trends, direct relations between sea surface temperature and heat gain are produced. From the Middle Atlantic Bight to Greenland sea surface temperature decreased rapidly presumably through cold water advection causing a large drop in the saturated mixing ratio at the air-sea interface, a decrease in the latent heat flux and a resulting increase in the heat gain by the ocean. Over nearly all of the rest of the North and South Atlantic Ocean the trend of the heat gain was negative. Over most of the North Atlantic the decrease in heat gain was caused by meteorological events and hence the sea surface temperature also decreased. Over the South Atlantic the sea temperature trend was positive and produced a negative trend of the heat gain by the ocean.

In press: Monthly Weather Review.

Supported by: NSF Grant ATM77-01475.

THE COASTAL LONGSHORE PRESSURE GRADIENT: TEMPORAL VARIATIONS AND DRIVING MECHANISMS

Robert R. P. Chase

Along the northern coastal boundary of the Mid-Atlantic Bight, synthetic subsurface pressure records derived from 1975 tide gage and airway weather observations are examined for fluctuations having monthly time scales. Additional calculations are performed to determine the factors controlling variance in these pressure data. Similar analyses are applied to the longshore gradient in synthetic subsurface pressure. Results of the study indicate that synthetic subsurface pressures are controlled by three mechanisms, two each at either end of the coastal segment. Fluctuations in Gulf Stream position have a significant effect on monthly mean pressures, which are uniform along the coast. At the western end of the coastal segment, east-west winds are also important, while changes in water density contribute significantly to subsurface pressure variance at the eastern end. Coastal steric differences are found to be a minor contributor to monthly fluctuations of longshore pressure gradient, while the coastal mean east-west winds effect a linear response in the gradient. Using this relationship and upon removal of geodetic leveling errors, the annual mean longshore sea surface slope is calculated to be  $1.6 \times 10^{-7}$ , forming a westward pressure gradient along the northern boundary of the Mid-Atlantic Bight.

Published in: Journal of Geophysical Research 84: 4898-4904, 1979.

Supported by: The Leopold Schepp Foundation, W.H.O.I., and Brookhaven National Laboratory.

LONGSHORE PRESSURE GRADIENTS CAUSED  
BY OFFSHORE WIND

Gabriel T. Csanady

Observations of currents 12 km south of the Long Island coast shows that strong off-shore winds could generate considerable long-shore non-tidal flow well below any surface Ekman drift. A momentum balance calculation in the longshore direction shows a surface level gradient of order  $10^{-6}$  to be the proximate cause of the longshore flow.

A very simple model of the observed phenomena is a sloping plane beach acted upon by cross-shore wind, varying sinusoidally in the longshore direction. With bottom friction parameterized by a linear law, a parabolic equation is found to govern steady state flow, expressing a balance of vorticity tendencies due to cross-isobath flow, curl of bottom stress, and any forcing. Calculated solutions for variable cross-shore wind show a trapped pressure field on the inner shelf which controls the transition between an essentially frictionless momentum balance on the outer shelf to frictionally dominated flow at the shore. Realistic estimates of the parameters entering the theory suggest that the longshore gradients associated with the trapped inner shelf field are of the correct order of magnitude to explain the generation of longshore flow by a system of cross-shore winds.

In press: Journal of Geophysical Research.

Supported by: The Department of Energy.

ON PRODUCTION AND DISSIPATION OF THERMAL  
VARIANCE IN THE OCEANS

Terrence M. Joyce

An integral relationship is derived expressing the total dissipation of thermal variance by oceanic microstructure in terms of the large-scale forcing at the ocean surface by air/sea heat exchange. The net heat gain by the ocean over warm water and heat loss over cold water is evaluated using zonal averages of annual oceanic heat fluxes and temperatures between 60° North and South latitudes. If thermal dissipation occurs in the upper ocean, with a scale depth of 600 meters, the

average dissipation  $\bar{\epsilon}$  is estimated to be  $10^{-7}$  ( $^{\circ}\text{C}$ )<sup>2</sup> sec<sup>-1</sup>. This value compares favorably with published observations of oceanic microstructure dissipation. The prediction is independent of any dynamical model of turbulent cascade from large to small scales in the ocean.

In press: J. Physical Oceanography.

Supported by: The Institut für Meereskunde, Kiel and NATO Travel Grant SV 19.

A RELATION BETWEEN THE T/S CURVE AND  
GLOBAL HEAT AND ATMOSPHERIC WATER TRANSPORTS

Henry M. Stommel and Gabriel T. Csanady

From historical data on the distribution of temperature and salinity on vertical sections across the oceans over complete latitude circles it is possible to test the compatibility of certain meteorologically determined meridional fluxes in the ocean of sensible heat and fresh water, as functions of latitude. It is also possible to check the proportion of this flux that each ocean basin carries separately.

The information from both these sources leads to estimates of the magnitudes and distribution of the meridional oceanic mass flux over the salinity-temperature plane, and yields some indication of the probable physical processes operating (e.g. isopycnal mixing vs. large-scale advective currents).

In press: Journal of Geophysical Research.

Supported by: NSF Grant OCE78-18460.

RESPONSE TO WIND FORCING IN THE UPPER OCEAN

Robert A. Weller

An attempt was made to observe in the upper ocean the response of the horizontal velocity field to forcing by the local wind. Measurements of the horizontal velocity in the upper 150 meters of the ocean were made by profiling with vector measuring current meters from the Research Platform Flip as it drifted off the coast of California in January 1977. The velocity data showed the presence of a surface layer, approximately 50 meters deep, in which motion at frequencies lower than .1 cph was coherent with the wind stress. The relation of the wind stress to the change in velocity with depth (or shear) was examined using rotary cross spectral analysis. The shear in the surface layer was related to the local wind

stress, and to a surprising extent the structure of the response at low frequencies agreed with the predictions of a rather simple linear model.

Supported by: ONR Contract N00014-75-C-0152 and W.H.O.I. Postdoctoral Fellowship.

#### INSTRUMENTAL NOTES

##### AIR DEPLOYMENT OF SATELLITE-TRACKED DRIFTERS

Robert E. Cheney, Philip L. Richardson  
and Barry P. Blumenthal

Six free-drifting buoys tracked by the Nimbus 6 satellite were successfully launched by C-130 aircraft in a series of deployments during 1977-79. All were launched in Gulf Stream rings in an attempt to follow them remotely for long periods of time (months). This represents the first operational test of this recently developed technique and paves the way for a variety of other ocean applications.

Supported by: ONR Contract N00014-74-C-0262, NR 083-004.

##### JASIN AND MILE CURRENT METER INTERCOMPARISONS

David Halpern, Robert A. Weller,  
Melbourne G. Briscoe,  
Russ E. Davis and James R. McCullough

We have tested four different kinds of current meters on three different classes of moorings in the upper 100 m of two different deep water sites during low and high wind conditions and low and high current conditions. By comparing the spectra and coherences between similar instruments on different moorings, and between different nearby instruments on the same mooring, we conclude that present ideas of the sources of errors due to mooring motion are reasonable, that low frequency measurements in the mixed layer are quite feasible, that high frequency measurements in the mixed layer require our best instruments and moorings, and that measurements beneath the mixed layer, especially of high frequencies, can only be done well on subsurface moorings.

The Vector Averaging Current Meter (VACM) under a surface-following mooring like a traditional toroid gives good results at low frequencies in the mixed layer, and increasingly poorer results at all frequencies beneath the mixed layer. Two newer instruments

(i.e., an acoustic current meter and a propeller vector measuring current meter) are somewhat better but are still imperfect below the mixed layer.

Supported by: NOAA Environmental Research Laboratories and ONR Contracts NR 083-431; N00014-75-C-0152, NR 083-004; & N00014-76-C-0197, NR 083-400.

##### COMPARISON OF POLAR AND GEOSTATIONARY SATELLITE INFRARED OBSERVATIONS OF SEA SURFACE TEMPERATURES IN THE GULF OF MAINE

Richard Legeckis, Eugene Legg and  
Richard Limeburner

A comparison is made between the polar orbiting (NOAA) and the geostationary (GOES) satellite infrared observations of the sea surface temperatures in the Gulf of Maine between 23 May and 6 June 1978. False color image enhancement is used to demonstrate that both satellites are capable of detecting the large scale surface patterns associated with the Gulf Stream and the sea surface temperature fronts in the vicinity of Georges Bank and Nova Scotia. Coastal radiosonde profiles are used to estimate the correction for atmospheric attenuation of the infrared radiation. The main difference between the range of surface temperatures detected by the satellites is due to their different spatial resolution: 1 km for the NOAA and 8 km for the GOES. The temperatures recorded by the GOES are 2 to 3C lower than those obtained by the NOAA satellite; this is due to a GOES calibration offset. The comparison of the NOAA data with ship observations off Nantucket indicate that, at a sea surface temperature range of 6 to 7C, the satellite and ship observations agree within 1C. A similar comparison in the Gulf Stream indicates that the NOAA measurements are 2 to 3C lower than the *in situ* observations. A comparison of Maul and Sidran and Weinreb and Neuendorffer models for absorption of infrared by atmospheric water vapor shows a significant difference in the predicted temperature deficit. Due to measurement uncertainties, it was not possible to resolve the discrepancy between the models.

Supported by: The Department of Commerce, NOAA Office of Sea Grant, numbers 04-7-158-44104 & 04-8-M01-149.

##### SPECTRA OF FREQUENCY COUNTING DIGITIZATION ERRORS

Richard E. Payne and Woollcott K. Smith

The digitization error for averaging by frequency counting is analyzed for the case

in which successive recording intervals are separated by a time much smaller than the period of the frequency being counted. It is shown that the power density of the noise spectrum is given by  $G_K = \Delta(\alpha^2/3)(1 - \cos 2\pi \Delta\nu)$  where  $\Delta$  is the length of the recording interval,  $\alpha$  is the conversion factor from signal to counts defined by  $N = X/\alpha$  where  $N$  is counts and  $X$  is signal, and  $\nu$  is frequency. This result is in contrast to the white noise that results from digitization error when the recording intervals are well separated in time.

Supported by: ONR Contract N00014-76-C-0197, NR 083-400.

#### TECHNICAL REPORTS

##### ATLANTIS-II (CRUISE 102) MOORED AND SHIPBOARD SURFACE METEOROLOGICAL MEASUREMENTS DURING JASIN 1978

Melbourne G. Briscoe, Carol A. Mills,  
Richard E. Payne and Kenneth R. Peal

During cruise 102 of the R/V Atlantis-II in the Joint Air-Sea Interaction Project (JASIN), surface meteorological data were gathered by Woods Hole Oceanographic Institution personnel from two moored buoys and from the ship. One buoy (JASIN W2/WHOI 651) carried a Vector Averaging Wind Recorder (VAWR) and a Vector Measuring Wind Recorder (VMWR); these instruments provided 18 days of inter-comparison data and 38 days of meteorological data from 30 July to 6 September 1978. The other buoy (JASIN H2) carried a VMWR and gave 25 total days of data from 16 July to 10 August, and from 26 August to 1 September. A PET computer, hardwired to sensors positioned on the ship, displayed data that were logged during both legs of the cruise. Manual data were gathered by the science watches. This report describes the PET system, and displays and compares all the data. VAWR hourly meteorological data are listed for the 38 day period. Scientific interpretation of these data, such as calculations of heat fluxes, will be published separately.

Prepared for: NSF under Grants OCE77-25803 & OCE76-80174 and ONR under Contract N00014-76-C-0197, NR 083-400.

##### ARCHIVED TIME-SERIES OF ATLANTIC OCEAN METEOROLOGICAL VARIABLES AND SURFACE FLUXES

Andrew F. Bunker and Roger A. Goldsmith

Time-series of monthly averages of latent, sensible and radiational heat fluxes and momentum fluxes at the surfaces of the North and

South Atlantic Oceans were calculated from ship weather observations. These fluxes, together with values of meteorological variables have been averaged over entire Marsden squares ( $10 \times 10^\circ$  squares) for all months from January 1948 through December 1972. The method of computing fluxes from ship weather observations, listing of variables averaged, addition of sea-ice coverage of sub-polar regions, correction of albedos for the presence of sea ice, correction of infrared radiational exchange for humidity conditions of the upper atmosphere, and format of the data on magnetic tapes are described. Statistics of the fluxes and variables have been computed. Standard data tapes containing these time series and statistics are available.

Prepared for: The Climate Dynamics Research Program, Div. of Atmospheric Sciences, NSF under Grant ATM77-01475.

##### STD OBSERVATIONS IN THE SOUTHWEST ATLANTIC FROM CRUISE 16, LEG 9 OF THE R/V CONRAD AND CRUISE 7-75 OF THE ARA ISLAS ORCADAS

Daniel T. Georgi, Anthony F. Amos,  
K. Esteban Draganovic and Mary E. Raymer

Continuous salinity-temperature-depth (STD) data from two cruises in the South Atlantic are presented in both tabular and graphic form. Thirty-seven of the stations were made during the R/V Conrad cruise 16, leg 9, March 29 to April 23, 1973 and 20 stations on the ARA Islas Orcadas cruise 7-75, October 30 to December 20, 1975.

Prepared for: NSF under Grants OCE76-81149 and OCE79-04545.

##### HYDROGRAPHIC STATION DATA OBTAINED IN THE VICINITY OF NANTUCKET SHOALS, MAY, JULY, SEPTEMBER 1978

Richard Limeburner and Robert C. Beardsley

Three cruises were made during May, July, and September 1978, to measure the regional hydrographic structure in the vicinity of Nantucket Shoals on the New England Continental Shelf. A summary of the hydrographic observations made during Cruises NS1, NS2, and NS3 on the R/V Edgerton is presented in graphic form.

Prepared for: Department of Commerce,  
NOAA Office of Sea Grant under Grants  
04-7-158-44104 & 04-8-M01-149.

NEAR-SURFACE OCEAN CURRENT SENSORS:  
PROBLEMS AND PERFORMANCE

James R. McCullough

When current meters are used to measure mean horizontal currents in surface gravity waves, immunity to the vertical component of flow is important, even though the net vertical flow averages to zero and is normal to the desired horizontal components. A technique is presented for estimating the magnitude of the errors introduced by imperfect rejection of the off-axis flows (cross-talk) from laboratory measurements of the current meter "vertical-cosine-response." The predicted dynamic response is shown to compare favorably with laboratory measurements. The measured steady state vertical-cosine-response functions for several practical current sensors are summarized and used to estimate the magnitude of wave-induced errors in horizontal mean current measurements. A new dye technique for evaluating near-surface current meter performance in waves is shown.

Prepared for: The Working Conference on Current Measurements sponsored by the NOAA Office of Ocean Engineering with the Delaware Sea Grant College Program.

ATLANTIS-II (CRUISE 102) PRELIMINARY CTD DATA  
FROM JASIN 1978

Nancy J. Pennington and Melbourne G. Briscoe

102 profiles of conductivity, temperature, and depth (pressure) (CTD) were taken in the JASIN area northwest of Scotland in July-September 1978. These stations consisted of single and yo-yo profiles. The data set includes 14 stations taken near Anton Dohrn Seamount at 57°30'N, 11°W. Plotted profiles of temperature, salinity, sigma-theta, and buoyancy frequency, and a listing of the data, are included for most stations.

Prepared for: ONR under Contract N00014-76-C-0197, NR 083-400 and NSF under Grant OCE77-25803.

FREE DRIFTING BUOY TRAJECTORIES IN THE  
GULF STREAM SYSTEM (1975-1978):  
A DATA REPORT

Philip L. Richardson,  
Jeffrey J. Wheat and David P. Bennett

From 1975 to 1978, thirty-one satellite-tracked free-drifting surface buoys were launched in the Gulf Stream system. Most of

these buoys were launched in cyclonic rings, as part of an interdisciplinary Gulf Stream ring experiment. Other buoys were launched in anticyclonic rings and the Gulf Stream itself; one buoy was launched in a cyclonic Kuroshio ring. The basic data set consists of buoy trajectories and sea surface temperature and velocity measurements along trajectories.

The main results consist of a series of 19 buoy trajectories in rings from which the movement of rings is inferred and a series of 20 buoy trajectories in the Gulf Stream. Rings frequently coalesced with the Gulf Stream, and some reformed as modified rings. The trajectories of buoys in the Stream reveal that at times surface currents are strongly influenced by topographic features such as seamounts and ridges. Most buoys in the Stream continued to move eastward until they reached the vicinity of the Grand Banks (50°W) where they rapidly fanned out, some moving northward, others eastward across the mid-Atlantic Ridge, still others southward and westward.

Prepared for: ONR under Contract N00014-74-C-0262, NR 083-004 and NSF under Grants OCE75-08765 & OCE77-08045.

A COMPILATION OF MOORED CURRENT METER DATA,  
WHITEHORSE PROFILES AND ASSOCIATED  
OCEANOGRAPHIC OBSERVATIONS.  
VOLUME XX (RISE ARRAY, 1974)

Ann Spencer

Current and temperature measurements are presented from instruments deployed during 1974 on the continental rise (36-40 degrees north, 69-70 degrees west). Current meters were set primarily at depths of 200 and 1000 meters above the bottom, and all the records were of 9 months duration. Basic data are displayed as scatter plots, progressive vector diagrams, spectral plots and time series plots; statistical quantities are displayed in tables. Filtered time series are shown in composite displays. Data from a vertical current profiler, the 'whitehorse', are shown as basic profiles of current components and filtered, averaged vector profiles. Selected CTD data are included and displayed as plots of potential temperature and salinity versus pressure, and as temperature-salinity diagrams.

Prepared for: ONR under Contracts N00014-74-C-0262, NR 083-004 & N00014-76-C-0197, NR 083-400 and NSF under Grant OCE74-01282.

A COMPILATION OF MOORED CURRENT METER DATA  
AND ASSOCIATED OCEANOGRAPHIC OBSERVATIONS,  
VOLUME XIX (POLYMODE ARRAY I DATA)

Ann Spencer, Carol A. Mills  
and Richard E. Payne

Summaries of observations from moored stations taken during POLYMODE Array I are presented. Currents and water temperatures were measured at various depths, including 500, 800, 1000, 2000 and 4000 meters. Data series are of 9 months duration from August 1974 to May 1975. Low passed east and north current components are displayed as vector stick diagrams and progressive vector plots. Basic 1-hour current meter and temperature data are displayed as time series plots, spectral plots and in statistical tables. Selected CTD data are presented as potential temperature and salinity values plotted against pressure, and as temperature-salinity diagrams.

Prepared for: ONR under Contracts N00014-66-C-0241, NR 083-004; N00014-74-C-0262, NR 083-004 and NSF under Grants GX-29054 & OCE75-03962.

A COMPILATION OF MOORED CURRENT METER AND  
WIND RECORDER DATA, VOLUME XVIII  
(JASIN 1978, MOORINGS 651-653)

Susan Tarbell, Melbourne G. Briscoe  
and Robert A. Weller

Summaries of current and temperature measurements from three moorings in the 1978 Joint Air-Sea Interaction Project (JASIN) are presented; the moorings are WHOI/JASIN numbers 651/W1, 652/W2, and 653/W3. The instruments were either Vector Averaging Current Meters (VACM), Scripps Institution of Oceanography Vector Measuring Current Meters (VMCM), or Neil Brown Acoustic Current Meters (ACM). Displays include time series, histograms, progressive vector diagrams, scatter plots, and spectra; statistics are given for the entire deployment period (some 40 days) and for each 5-day segment.

Additional measurements include pressure and vertical temperature gradient. Wind records and other meteorological observations from one of the moorings are given, as well as partial wind records from another JASIN mooring (H2).

Prepared for: ONR under Contracts N00014-76-C-0197, NR 083-400 & N00014-75-C-0152, NR 083-005 and NSF under Grant OCE77-25803.

A COMPILATION OF MOORED CURRENT METER DATA  
AND ASSOCIATED OCEANOGRAPHIC OBSERVATIONS,  
VOLUME XXII (1973 OBSERVATIONS)

Susan A. Tarbell and Richard E. Payne

Current and temperature measurements from instruments on moorings set in 1973 at Site D and the Muir Seamount are presented. Both horizontal and vertical arrays are presented using low-passed filtered data. The basic time series from individual current meters are displayed with statistical tables, spectral diagrams, progressive vector plots, and plots of variables versus time.

Prepared for: ONR under Contract N00014-76-C-0197, NR 083-400.

DIAGNOSIS AND CORRECTION OF MALFUNCTIONAL  
BEHAVIOR IN DEEP SEA REVERSING THERMOMETERS

Geoffrey G. Whitney, Jr.

The nomenclature, morphology and functioning of deep sea reversing thermometers are identified and explained. The various types of malfunctions, nonfunctions and other aberrations are defined, and detailed instructions are given for the procedures used to restore normal functioning to the extent possible. Advice is given regarding the use, handling, storage and transportation of these instruments so as to avoid damage and actions which might cause malfunctions to occur.

Prepared under the support of the Woods Hole Oceanographic Institution.

# MARINE POLICY and OCEAN MANAGEMENT

MARINE POLICY  
AND OCEAN MANAGEMENT PROGRAM

Included in the abstracts submitted by the marine policy group are a number of papers which have been issued as "W.H.O.I. Technical Reports". We have chosen this medium of publication because there are no appropriate published journals that cover the varied subjects addressed by the marine policy group.

Support: All work reported in the following papers was prepared under the Woods Hole Oceanographic Institution's Marine Policy and Ocean Management Program, which is supported in part by private funds, by a grant from the Pew Memorial Trust, and as part of the Institution's Coherent Sea Grant Program, sponsored by the Office of Sea Grant, Department of Commerce, under Grants #04-MO1-149 and #NA 79AA-D-00102.

COASTAL ENERGY IMPACT PROGRAM BOUNDARIES  
ON THE ATLANTIC COAST: A CASE STUDY  
OF THE LAW APPLICABLE TO LATERAL  
SEAWARD BOUNDARIES

Donna R. Christie

The question of lateral seaward boundaries between States has been of little importance until recent decades; the interest in such boundaries between states has been even less. The extension of sovereignty to the continental shelf and creation of 200 mile fishery and economic zones have made lateral seaward boundary delimitation a critical issue in international law. Within the United States, speculation as to the extension of the territorial sea to 12 miles and, more importantly, development of resources on the continental shelf have recently made interstate seaward boundaries important in questions of conflict of law and in allocation of funds under the Coastal Energy Impact Program (CEIP). A state's allocation of CEIP funds is determined through a complicated formula based largely on the amount of continental shelf acreage adjacent to a state. The CEIP requires that if no state seaward boundary exists, a state's adjacent continental shelf acreage shall be determined by drawing boundaries according to "the applicable principles of law, including the principles of the Convention on the Territorial Sea and Contiguous zone, ....". The meager United States case law that exists on seaward boundaries indicates that international law and conventions are among the "applicable principles of law." Because of the applicability of international law and conventions and the fact that few of the boundaries are actually settled, the Atlantic coast of the United States presents an excellent case study of the legal and equitable problems presented in extending lateral seaward boundaries between adjacent states.

This study will discuss applicable international and national law, the position of the individual states concerning the extension of their boundaries and possible solutions to the boundary dilemma. The effect of any inconsistency which might arise between boundary delimitations for the purpose of CEIP allocations and boundaries for purposes of applicability of state law under the Outer Continental Shelf Lands (OCSL) Act will also be discussed briefly. Finally, this study will analyze the appropriateness of this boundary drawing exercise as a method for allocating CEIP funds.

In Press: Virginia Journal of  
International Law.

REGULATION OF INTERNATIONAL JOINT VENTURES  
IN THE FISHERY CONSERVATION ZONE

Donna R. Christie

In 1976 the United States enacted the Fishery Conservation and Management Act (FCMA) which extended exclusive fishery management authority to 200 nautical miles off the nation's coast. The legislation was designed not only to maintain fish stocks and rebuild stocks of overfished species, but also to promote domestic commercial and recreational fishing by establishing a national priority system. The possibility of so-called "joint ventures" in which fish harvested by United States fishermen would be delivered to foreign processing vessels in the fishery conservation zone (FCZ) was perceived as a loophole in the FCMA. Onshore processors demanded that the FCMA be amended to recognize that the fishery conservation zone was established to promote the development of the entire fishing industry, not only the fishermen, and to limit joint ventures which hindered the development of new onshore processing capacity. A hastily passed amendment to the FCMA in the summer of 1978 created a United States processor preference for American harvested fish similar to the fishermen's priority in the FCZ; however, the amendment also specifically authorized joint ventures for that part of the domestic harvest which the United States processors have no capacity or intention to process.

This paper will present the background of the joint venture amendment and analysis of the major problems involved in implementing the legislation. Current joint ventures and their effect on the United States fishing industry will also be discussed.

In Press: Georgia Journal of Inter-  
national and Comparative Law.

THE ADMINISTRATIVE POLICY PROCESS  
FOR SCIENCE: A CASE STUDY OF  
ORGANIZATIONAL ENVIRONMENTAL  
DYNAMICS

Peter Francis Hooper

Submitted to the University of Connecticut on June 27, 1979, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

The research is a case study of the policy process for a federal agency that supports large scale basic scientific investigations. The agency studied is the

Office for the International Decade of Ocean Exploration (IDOE) in the National Science Foundation (NSF). The IDOE is a ten-year program (1971 - 1980) for the support projects that, it is expected, will lead to more enlightened preservation of the ocean environment, improved environmental forecasting, and better management of marine mineral exploitation.

The study adopts an institutional approach, focusing on the organizational and clientele factors that shaped the program's development and implementation. The principal finding is that although originally undertaken as a major innovative science-non-science enterprise with political, economic, and scientific implications, the IDOE was transformed and scaled-down into one more consonant with the routinized expectations of the marine science community, and assimilated into the typical NSF mode of operation.

WHOI Reference No. 79-69.

EXPERIMENTAL LOBSTER RANCHING IN MASSACHUSETTS

Thomas Hruby

Artificial shelters were deployed in the shallow waters of Massachusetts Bay in an attempt to stabilize and increase lobster catches. Shelters constructed with concrete filled tires proved to be well suited for small scale ranching operations. Only two people were needed to make and deploy the shelters, and the capital costs were low. The animals quickly occupied shelters on sandy bottoms but not on rocky ones, and when fish wastes were provided as food in the former habitats, an increase was noted in trap captures. However, stable populations could not be maintained in the experimental areas for the lobsters were found to be continually moving. In October and November a general offshore trend was noted and tagged lobsters moved from a depth of 10 m to approximately 20 m.

In Press: Proceedings of the World Mariculture Society Meeting, January 22-26, 1979, Honolulu, Hawaii.

DOES SALT MARSH FERTILIZATION ENHANCE SHELLFISH PRODUCTION? AN APPLICATION OF FLOW ANALYSIS

Thomas M. Leschine and John T. Finn

The method of flow analysis, which is similar to economic input-output analysis, is presented as a means of making flow models of ecological systems more useful to environmental managers. As an illustration, the question of the extent to which nitrogen fertilizer added to Spartina salt marsh sediments can enhance shellfish growth is considered. Nitrogen flow models of both the Barataria Bay salt marsh complex of coastal Louisiana and the Sippewissett Marsh of western Cape Cod are analyzed. The analysis shows the transfer of added nitrogen to shellfish growth via Spartina growth, decomposition and detrital feeding to be considerably less efficient than its transfer to Spartina growth itself. These results are similar for both marsh systems, despite their great physical differences and despite the inclusion of considerably more microbial processing of nitrogen in the Barataria Bay model than in the Sippewissett models considered. The results suggest that the most efficient mechanism by which added nitrogen could enhance shellfish growth in salt marshes may have to bypass the route through Spartina uptake, growth, death and decomposition.

In Press: Environmental Management

A PROFILE OF WETLANDS REGULATION IN COASTAL MASSACHUSETTS TOWNS: LOCAL REGULATORY ACTIVITY AND THE PUBLIC PERCEPTION OF EFFECTS

Thomas M. Leschine and Stephen R. Cassella

This paper discussed an ongoing study of the administration of state and local wetlands regulations in several coastal Massachusetts towns. The emphasis is on the extent to which current regulations, implemented by both state and local jurisdictions, are affecting the allocation of wetlands resource uses at the local level. Two main paths of inquiry are developed. The local mechanisms which have evolved in response to state mandates, largely zoning plans and permit systems for regulating construction activity, are described. Their effectiveness in

channeling town construction away from modes which diminish the general utility of wetlands to the community at large is discussed through a comparison of local permit issuance patterns to local trends in construction and land development.

The preliminary results of a survey of the affected population of wetlands property owners are also presented. This survey, intended to complement the analysis of town regulatory activity, attempts to establish a socio-economic profile of wetlands property owners. This profile includes such factors as the distribution of wetlands ownership by number and type of parcels owned, and of past, present and intended future uses of wetlands properties by present owners. This survey also examines property owners' perceptions of the ways in which wetlands regulations have affected them, and their strategies for the use of their property in light of these perceptions.

In Press: Proceedings of the Fifth Annual Meeting of the Coastal Society "Resource Allocation Issues in the Coastal Environment," November 7-8, 1979, Newport, Rhode Island.

ABSTRACTS OF READINGS IN FISHERIES  
MANAGEMENT AND COMMON PROPERTY  
RESOURCES

Yoshiaki Matsuda

Since the passage of Public Law 94-265--the Fishery Conservation and Management Act of 1976 - there has been increased awareness among the public and among academicians in the problems of common property resources. The literature reviewed and summarized here deals with a number of the major issues related to common property resource management, and with the particular management technique most often mentioned for fisheries: limited entry. As with any review of the literature, it is not inclusive; rather it attempts to cover the literature that is frequently referenced and/or basic to an understanding of common property resource management.

WHOI Reference No. 79-36.

Principal support: NOAA Contract #03-78-D01-72 (prepared for NMFS).

FISHERIES POLICY AND THE UNDERDEVELOPMENT  
OF INSHORE PACIFIC MEXICO

James R. McGoodwin  
Development of shrimp-export industry

brought about the underdevelopment of Pacific Mexico's inshore fisheries. The rural fishery of south Sinaloa provides a case in point, as well as a point of departure for considering fisheries development and management policy for similar fisheries in certain other less developed countries.

WHOI Reference No. 79-44.

AQUACULTURE DEVELOPMENT IN RURAL  
ATOMISTIC SOCIETIES

James R. McGoodwin

For technological innovations to succeed in alleviating problems of rural underdevelopment they must be appropriate to the sociocultural context in which they are to be developed. Technical and economic feasibility alone is not enough. Atomistic rural societies -- which are societies lacking in supra-household organizational entities -- are the most common societal type found in the impoverished rural regions of the less developed countries. Development efforts in such societies and especially those where shortage of food is an acute problem, should aim first at intensification and regularization of domestic food production by increasing the productivity of households. When considering aquaculture development, family-operated, house-site, subsistence-oriented ponds, which employ rudimentary technology, would seem an appropriate innovation in atomistic communities. The author's field experience in an atomistic community in rural Mexico provides perspectives for the discussion.

WHOI Reference No. 79-53.

MEXICO'S MARGINAL INSHORE PACIFIC  
FISHING COOPERATIVES

James R. McGoodwin

Following their establishment by the central government in 1933, Mexico's inshore Pacific fishing cooperatives enjoyed great prosperity. Today, however, they are marginal socio-economic entities, and many are failing. The inshore cooperatives in south Sinaloa state -- the first to be established along Mexico's Pacific coast -- are examined as a case in point. Their decline was brought about by a multiplicity of factors--corruption, counter-productive technological innovations, natural catastrophe--as well as an underlying structural flaw in their organization: as State

instituted-and-controlled entities, they are not autonomous. Thus, as the central government developed economically more viable offshore shrimp-producing cooperatives, the inshore cooperatives were unable to respond competitively, and declined.

In Press: Anthropological Quarterly.

THE DECLINE OF MEXICO'S PACIFIC  
INSHORE FISHERIES

James R. McGoodwin

Following a cultural and economic history of the fisheries, the discussion focuses on the development of shrimp-export industry in this century, arguing that development of the industry's offshore sector brought about the dramatic decline of the inshore fisheries over the past three decades. Fisheries' management and development policy--for Mexico and other nations having similar fisheries--is the topic of the conclusion.

Published in: Oceanus 22(2):51-59,  
1979.

A LOT OF HEAT, BUT NOT MUCH LIGHT: AN  
ANTHROPOLOGIST LOOKS AT OFFSHORE OIL

Jane H. Nadel

Drilling for oil and gas offshore has come to be one of the more emotional issues of our time. While government and oil company spokesmen warn of dwindling supplies and rising prices, marine scientists, environmental activists and others worry about potentially irreversible damage to offshore and coastal environments and populations. It has become impossible to discuss any aspects of offshore exploitation without taking, or appearing to take, a stand in one camp or another. The media tend to present energy development issues as simple monoliths: big industry vs. the little guy, high-risk technology vs. fragile ecosystems, oil vs. fish, and economic development vs. economic disaster. In fact, none of these issues is simple or unambiguous. Perhaps the most complex and far-reaching issues are to be found onshore, where human communities must deal with the consequences of exploration, development, and production support services. In order to gain insight into the dynamics of some of these issues, we need more on-the-ground anthropological analysis of the social actors involved, and of their fields of action.

In Press: Anthropology and Environmental Planning.

OCEAN REGULATIONS: WHERE ARE WE GOING?

Susan B. Peterson

Recent changes and proposed changes in domestic and international ocean law are reviewed as they may affect man's uses of the ocean. Three areas of the Law of the Sea Negotiations - ocean mining, boundaries, and marine scientific research - are covered, as well as harvest of the living resources - anadromous fish, whales, highly migratory fish, aquaculture, coastal fisheries. The evolution of coastal zone management programs throughout the world and the growing concern with ocean pollution are described. Proposed domestic legislation for seabed mining, oil spill liability and shipping are also outlined.

In Press: Environment Magazine.

SOCIAL AND ECONOMIC PROBLEM AREAS FOR  
AQUACULTURE DEVELOPMENT IN THE  
COASTAL ZONE

Susan B. Peterson and Leah J. Smith

An approach to the solution of constraints on aquaculture development is suggested, especially as they affect the unique problems of coastal zone development: rapid change in use and value of wetlands, and establishment of property rights to the products of aquaculture development. The authors identify the kinds of information necessary for development and planning, and define the term "infrastructure" in social and economic terms. They make suggestions for future research to alleviate constraints on development on three levels -- individual enterprise, industries ancillary to the project, and national development as a whole.

In Press: Proceedings of meeting on  
Resource Use and Management of  
the Coastal Zones of the Asian  
Humid Tropics, December 18-21,  
1978.

INTERJURISDICTIONAL CONFLICTS IN FISHERIES  
MANAGEMENT: RESOLUTION THROUGH REGIONAL  
MANAGEMENT PLANNING

Alison Rieser

Allocation of fishery resources among competing user groups poses difficult technical and policy problems to fishery managers, especially where fish stocks are heavily exploited and objectives for their management include rebuilding of depleted stocks. Competition between nearshore and offshore

commercial fishermen and between recreational and commercial fishermen in both offshore and nearshore fisheries becomes inevitable when total catch limitations or quotas are imposed under conservation and management regulations. In the management of New England groundfish (cod, haddock and yellowtail flounder) and herring, the management plans developed by the New England Fishery Management Council and implemented by the Secretary of Commerce have established specific seasonal and area allocations of total annual catch quotas. These allocation schemes have attempted to provide equitable access to the regulated species to harvesting groups that are distinguished by different gear types, geographical access, and seasonal dependence upon the resource. At the same time these management plans attempt to restrict overall fishing effort to levels which are consistent with biological objectives, including stock rebuilding. The fragmented nature of the institutional framework for marine resource management contributes to the difficulties associated with the aforementioned distribution of economic benefits to different social groups. In fisheries management, the state and federal governments often have jurisdiction over species and fisheries which are present in both state waters and the federal Fishery Conservation Zone. The Fishery Conservation and Management Act of 1976, while a federal statutory authority, provides a regional fishery management process which centers upon the activities of Regional Fishery Management Councils. The establishment of federal regulations for the management of such inter-jurisdictional species as groundfish and herring under the new law has had the initial effect of exacerbating the institutional problems of concurrent state and federal jurisdiction over marine resources. Recently, however, cooperative arrangements between state and federal fishery management authorities have begun to be explored and state agencies have begun to improve their management capabilities and strategies for their nearshore fisheries. The regional management structure of the FCMA should be seen as a catalyst for cooperative interstate management of fisheries in state and federal waters. The structure should also be explored as a model for possible application to other resource allocation and management programs where overlapping jurisdiction exists.

In Press: Proceedings of the Fifth Annual Meeting of the Coastal Society "Resource Allocation Issues in the Coastal Environment," November 7-8, 1979, Newport, Rhode Island.

THE FISHERY CONSERVATION AND MANAGEMENT ACT  
AS A TOOL FOR MITIGATION IN OUTER  
CONTINENTAL SHELF PETROLEUM  
DEVELOPMENT

Alison Rieser and Judith Spiller

Georges Bank, on the Northwest Atlantic Continental Shelf, represents one of the world's most productive fisheries; yet, the adverse environmental effects associated with Outer Continental Shelf (OCS) petroleum development threaten this productivity. The potential for damage to fisheries stems from catastrophic events such as oil spills, pipeline breaches and well blowouts, but more certainly it comes from daily operational discharges and runoff drainage from drilling rigs and platforms. Such threats range from smothering, acute toxicity, uptake of heavy metals resulting potentially in physiological disruption, bioaccumulation and biomagnification to carcinogenicity and mutagenicity. Further, drilling activities often coincide with highly productive fishing areas and so preclude the use of these areas for fishing.

Current and proposed regulations applicable to OCS petroleum development inadequately protect critical fishery habitats on the Georges Bank. The Fishery Conservation and Management Act of 1976 (FCMA), through the regional Fishery Management Plans (FMP), provides a process for the definition and protection of these critical fishery habitats. On the Georges Bank, this operation involves the identification of spawning and prime grounds of species of concern and then the inclusion of these areas in the FMPs. Thus, by incorporating such critical areas into a FMP approved by the Secretary of Commerce, these areas would receive special consideration, so that the adverse effects of offshore development on fisheries would be minimized.

In Press: Proceedings of the Mitigation Symposium, July 17-19, 1979, Ft. Collins, Colorado.

ASSESSMENTS OF USES, ENVIRONMENTAL EFFECTS  
AND REGULATORY AUTHORITIES FOR THE MANAGEMENT  
OF GEORGES BANK: NON-OIL AND GAS ACTIVITIES

Part A: Analysis of Oil and Gas Regulation

Alison Rieser and Judith Spiller

In order to evaluate the effectiveness of the existing regulatory authorities in protecting the marine environment from the adverse effects of offshore petroleum acti-

vities, we have focused initially on the control of drilling mud discharges in OCS areas currently undergoing exploration or development and production. We have identified the major controls which are currently in effect or are proposed for areas on the Mid-Atlantic, Gulf of Mexico, and southern California OCS. In the final report, we will provide a detailed evaluation of these controls as they are being administered in active OCS areas. Based upon our conclusions from this portion of the study, we will describe appropriate controls for activities on Georges Bank. In this initial report we describe the basic authorities and examine the administrative process leading up to and resulting from the issuance by EPA's Region II Office of water discharge permits to exploratory drilling rigs in the Baltimore Canyon area of the Mid-Atlantic OCS. The second section of this Progress Report examines the necessity for controlling drilling discharges, including their effects on marine organisms. In addition, the second section examines the research findings on which current regulations rely, current research activities on the effects of drilling muds on marine organisms, and some area-specific recommendations for Georges Bank.

Part B: Examination of Pollution and Other Impacts Resulting From Ocean Uses

Daniel P. Finn

This section examines the existing regulatory framework applicable to tankers, including their operational discharges, spills, anchoring and other operations. Other sources of pollution for Georges Banks such as potential ocean dumping activities, transport of toxic chemicals and hazardous substances, sand and gravel mining, recreational uses and other activities are discussed. Finally, this part analyzes the options for site-specific management of Georges Bank based on the uses described here.

Principal support: NOAA Contract #NA-79-FA-C-00049.

THE FISHING LABOR MARKET IN TWO NEW ENGLAND PORTS

Leah J. Smith and Margaret E. Dewar

The labor markets for the fishing industry in Gloucester and Chatham are compared. The Gloucester fishing pool is dominated by fishermen of Italian extraction; their entry into fishing, movement among crew sites, progress to

the position of captain, and purchase of a boat are largely determined by family considerations. The Chatham fishermen and a small group of Gloucester fishermen participate in the fishing labor market in a very different way. More fishermen operate their own small boats (rather than working as crew on large boats); movements among fisheries are more frequent; skill development and financial resources are pursued on a more individual basis, although "natives" of the town have significant initial advantages in entering the fishing industry. The different reactions of the Italian Gloucester fishermen and the Chatham and other Gloucester fishermen are explored for several different management techniques; quotas, mesh size limitations, closed seasons, areas and limited entry.

Principal support: NOAA Contract #03-78-D01-69.

ENVIRONMENTAL MANAGEMENT OF OUTER CONTINENTAL SHELF PETROLEUM ACTIVITIES AND THE PROTECTION OF OFFSHORE LOBSTER

Judith Spiller

Environmental pollution associated with Outer Continental Shelf (OCS) oil and gas exploration and development on Georges Bank potentially threatens offshore lobster directly through the effects of smothering and of disruptions in breeding behavior and indirectly through reduction of marine water quality. Because a close relation exists between offshore lobster and near shore populations, damage to offshore groups could reduce population numbers near shore. Minimization of hazards to offshore lobster rests with detailed knowledge of their distribution, and then the development of stringent controls on OCS petroleum operations in areas of lobster concentration. Previously, information on distributions has been lacking; however, integration of National Marine Fisheries Service (NMFS) commercial data, NMFS survey data and discussions with lobstermen indicates that during the spring and summer, many lobsters migrate from the canyon heads bounding the southern edge of Georges Bank into shallower waters coincident with proposed tracts for OCS lease sale #42. During the period of migration, breeding occurs. In light of the effects of hydrocarbons and other drilling discharges on lobster, in areas of high lobster concentration during the critical breeding phase, restrictions on drilling discharges, deck drainage and release of produced waters

must be incorporated into OCS lease stipulations, National Pollutant Discharge Elimination System (NPDES) permits, and the Fishery Management Plan for lobster currently under development by the New England Regional Fishery Management Council.

In Press: Proceedings of the Fifth Annual Meeting of the Coastal Society "Resource Allocation Issues in the Coastal Environment," November 7-8, 1979, Newport, Rhode Island.

THE STRUGGLE FOR THE GLOBAL COMMONS

Per Magnus Wijkman

Recent international negotiations aim at distributing management and property rights to internationally shared resources among nation states. This paper explains that subdivision is inappropriate when property rights to parts of the resource cannot be enforced economically, its size is unknown, and its exploitation involves external economics. When many competitive firms exploit such common property resources public regulation of the resource is necessary. When many governments share the resource, the regulator must be endowed with supranational, coercive powers. The paper considers whether the management regimes proposed by the international negotiations concerning the continental margin, the deep seabed, the high seas, the Antarctic and outer space will lead to efficient resource utilization and equitable division of resource rents. It concludes that this appears unlikely and suggests a regime that will ensure efficient exploitation while allowing any distribution of rents that a majority of the international community desires.

Published in: Ekonomisk Debatt, 6: 385-392, 1979 (English version, 25 pp.).

THE STRUGGLE BETWEEN DEVELOPED AND DEVELOPING COUNTRIES OVER THE DEEP SEABED

and

NON-COASTAL STATES LOSERS

Per Magnus Wijkman

These two articles survey the unresolved issues facing the 8th session of the United Nations Law of the Sea Conference in 1979. They present the positions of the

major protagonists concerning the design of the deep seabed mining regime, the extent of coastal and non-coastal state fishing rights in the exclusive economic zone, and the delineation of the outer edge of the continental margin and the property rights to hydrocarbon resources.

Published in: Svenska Dagbladet, 1979 (Swedish newspaper).

THE EFFICIENCY OF CARGO RESERVATION AS AN INSTRUMENT OF UNCTAD'S SHIPPING POLICY

Per Magnus Wijkman

The United Nations Conference on Trade and Development has proposed an international convention allowing countries to reserve cargo that their foreign trade generates for vessels carrying their own flag (e.g. 40% for the sending and receiving country respectively and 20% for third countries). The purpose is to increase developing countries' share of world liner shipping tonnage, to increase their share of income generated by world liner shipping and, in particular, to redistribute monopoly profits where they exist from rich to poor countries, and to improve their balance of payments. This paper assesses the efficiency of this instrument in achieving these goals and quantifies the redistribution of world liner and bulk tonnage between nations that would result from universal application of the code. It concludes that cargo reservation is not a preferred policy instrument for any of these maritime policy goals.

Published in: Economic Institute for International Studies, Seminar Paper, 50 pages, Stockholm, 1979.

Additional support: The Bank of Sweden Tercentenary Foundation.

OUTER SPACE RESOURCES IN EFFICIENT AND EQUITABLE USE--NEW FRONTIERS FOR OLD PRINCIPLES

Clas G. Wihlborg and Per M. Wijkman

The geostationary orbit and the electromagnetic spectrum are common property resources. After reviewing their technical characteristics, the paper presents evidence that these resources are already scarce or will become scarce in the near future. It evaluates alternatives to replace the current regime under which user rights and rents are allocated on the principle of first-come, first served. A majority of countries consider this allocation inequitable and it is currently being

renegotiated through the International Telecommunications Union (WARC 79). The paper considers what regime best will combine efficiency with equity. It concludes that the market mechanism can achieve efficient use of these scarce resources if marketable, divisible, and indefinite user rights for the totality of the resources are instituted and if enforceable liability rules are defined. It suggests setting up an international management authority to auction user rights and to distribute the rents to its stockholders. Political negotiations would determine how shares in the authority are distributed between countries thereby satisfying considerations of equity without reducing efficiency. The suggested regime is applicable to other common property resources.

Published in: Institute for International Economic Studies,  
Seminar Paper No. 30: 1-30,  
Stockholm, Sweden, 1979.

FIRST U.S. NORTH ATLANTIC REGIONAL  
WORKSHOP ON REMOTE SENSING IN THE  
COASTAL AND MARINE ENVIRONMENT

Edited by James B. Zaitzeff, Peter  
Cornillon, David A. Aubrey

Following two days of intense review of remote sensing technology and applications to marine problems the conferees of the workshop were divided into three working groups: Coastal Processes and Management, Commercial and Recreational Fisheries, and Marine Physical Processes. These working groups deliberated on two problem areas: (1) the data needs of the group, and (2) potential application of remote sensing in addressing these data needs. The conclusions and recommendations of the working groups are summarized with a focus towards identifying common elements in the various observations made. These are (1) there is user need for access to regional expertise and to a regional remote sensing information/analysis and processing center, (2) there is a need for a remote sensing data atlas for the U.S. Northeast region which would summarize on a monthly basis such quantities as: cloud cover, ocean color, water mass locations, sea ice and sea surface temperature, (3) there is a need for near-real time meteorological and oceanographic forecasts, development of instrumentation for receiving remotely sensed data while at sea, and increased use of satellites as communication platforms capable of relaying oceanographic variables measured by buoys or other remote acquisition platforms, and

(4) there is a need for the development of a formal regional communication mechanism to insure dialogue between the U.S. North Atlantic regional users of remote sensing data and the responsible agencies for developing and operating remote sensing technology and of the suppliers of its data and information products.

The Workshop was held on May 30-June 1, 1979 at the University of Rhode Island.

Sponsored by: The National Aeronautics and Space Administration, WHOI/MPOM, University of Rhode Island, Center for Ocean Management Studies.

SALMON FISHERS OF THE COLUMBIA

Courtland L. Smith

For more than a century, fishermen of various ethnic and social backgrounds have sought to make the Columbia River salmon resource their own. Indians, gill netters, trapmen, seiners, fishwheelers, dipnetters, trollers, and sports anglers have competed with one another for salmon. Over the years, many different methods of fishing have developed in response to changes in the river and in social economic, and political conditions.

Using recently acquired information, this book carefully documents the changes in the Columbia River salmon fishery since the late 19th century and analyzes the factors that have caused these changes. The book provides a comprehensive historical, social, and economic picture of the canned salmon industry.

Published by Oregon State University Press, 117 pages, 1979.

Principal Support: Oregon State University.

# GRADUATE STUDENTS

GRADUATE STUDENTS

Abstracts of papers and theses submitted in 1979 by graduate students of the Woods Hole Oceanographic Institution Doctoral Degree Program and the Woods Hole Oceanographic Institution/Massachusetts Institute of Technology Joint Program in Oceanography/Oceanographic Engineering. Other papers authored or coauthored by graduate students are included in the departmental sections. Students are indicated by an asterisk in the Author Index.

GEOLOGY OF THE PASSIVE MARGIN OFF NEW ENGLAND

James Albert Austin, Jr.

Submitted to the Department of Earth & Planetary Sciences, Massachusetts Institute of Technology, and to the Department of Geology and Geophysics, Woods Hole Oceanographic Institution, on December 1, 1978, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Abstract

The results of a detailed geophysical investigation conducted by the Woods Hole Oceanographic Institution in 1975 have been used in conjunction with other available information to reconstruct the geologic history of the passive continental margin off New England. Rifting between northeastern North America and Morocco during the Middle-Late Triassic produced a complex series of horsts and grabens in Precambrian/Paleozoic crust. Intra-rift sediments consist of clastics, evaporites, and volcanics. Continental separation occurred and sea-floor spreading began 195-190 my B.P. The boundary between "normal" continental crust and crust radically altered by fracturing and intrusion may be represented by a pronounced basement "hinge zone". Prior to margin subsidence, extensive subaerial erosion carved a "break-up unconformity"-reflector "K" which truncated preexisting rift structures and which must be approximately the same age as the oldest oceanic crust. Within the overlying "drift" sediments, six acoustic horizons have been regionally traced and correlated with strata sampled by a well drilled on the western Scotian Shelf. The total sediment thickness of both rift and drift sequences beneath Georges Bank may be 13 km, of which more than 80% is Jurassic in age. A Mesozoic reef/carbonate platform complex situated on the outer shelf-upper slope was an effective sediment barrier until the early Late Cretaceous, when prograding clastics buried the complex. This carbonate build-up and its basement foundation of altered continental or oceanic crust are responsible for the geographic position and steepness (5-8°) of the present continental slope south of Georges Bank.

Supported by: NSF IDOE IDO grant 74-04094; NSF grant OCE 77-09421; Office of Sea Grant contracts 04-7-158-44104 and 04-8-M01-149; U. S. Department of State 1722-620214; WHOI.

INTAKE FLOW FIELDS FOR A ZOOPLANKTON PUMP SAMPLING SYSTEM

James Ray Brooks

Submitted to the Department of Ocean Engineering on September 11, 1979 in partial fulfillment of the requirements for the degrees of Master of Science and Oceanographic Engineer.

Abstract

The flow fields entering intake forms oriented into a steady flume flow has been observed and quantified. This data is applied to a model of zooplankton sampler performance, to predict the fraction of the sampled fluid from which no animals will escape under conditions similar to those of the tests. Flume flow speeds ( $\approx 5$  cm/s) and intake pumping rate ( $\approx 33$  gal/min) are scaled by a factor of 20 in the model, while test form dimensions (4 and 7 inch throats and 12 inch outside diameters) are considered to be full-size for the prototype pump samplers. The data presented can be applied to other flow and geometrical scales.

The 'lethal cone' and critical fluid deformation rate envelopes are evaluated for eleven intake forms: pointed, bullet-shaped, funnel-shaped, rounded and square-ended. The sharply-pointed intake performed best, for tow speed  $\approx 100$  cm/s, swimming speed = 30 cm/s and  $D_c = 1.0$  sec<sup>-1</sup>. 'Sure capture' is predicted in 83% of the sampled water. The four funnel-shaped forms follow consecutively in a rank ordering, with efficiencies of 77% to 68%.

Supported by: Woods Hole Oceanographic Institution.

THE INFLUENCE OF DIFFERENTIAL PRODUCTION AND DISSOLUTION ON THE STABLE ISOTOPE COMPOSITION OF PLANKTONIC FORAMINIFERA

Jonathan Erez

Abstract

Planktonic foraminifera from plankton tows, sediment traps and sediments from the central North Atlantic were studied in order to understand how they acquire their oxygen and carbon isotope compositions. Shallow dwelling planktonic foraminifera (mostly spinose species), collected in plankton tows in the photic zone, show light isotopic compositions possibly in slight negative deviation from oxygen isotopic equilibrium.

Radioactive tracer experiments using <sup>14</sup>C and <sup>45</sup>Ca were conducted on shallow dwelling benthonic foraminifera and hermatypic corals.

They show that photosynthesis of symbiotic algae within these organisms increases the amount of metabolic  $\text{CO}_2$  incorporated into the skeleton which consequently becomes isotopically lighter. Because shallow swelling planktonic foraminifera contain symbiotic algae it is suggested that their light isotopic compositions are also caused by photosynthetically enhanced incorporation of metabolic  $\text{CO}_2$  in the skeleton.

Planktonic foraminifera collected in sediment traps and sediments show heavier oxygen isotope compositions that are in equilibrium for  $\text{CaCO}_3$  deposited in the photic zone. At the same time the weight/individual for these foraminifera is almost doubled compared to those from plankton tows. I suggest that these apparent equilibrium compositions are achieved by a combination of light, perhaps non-equilibrium skeletons deposited in the photic zone and isotopically heavier calcite deposited below the photic zone. The latter being isotopically heavy because temperatures are lower, metabolic activity is reduced, and photosynthesis by the symbiotic algae stops.

Dissolution of planktonic foraminifera on the ocean floor removes first the light-weight thin shelled individuals of a species population. Because these individuals are isotopically lighter, the isotopic composition of the surviving population is heavier.

The scheme described above is applied to explain the effect of dissolution on the glacial-interglacial amplitude of the Pleistocene isotopic record in the Atlantic and the Pacific Oceans. The timing of dissolution cycles in the two oceans is out of phase. Dissolution during the glacial in the Atlantic and during the interglacial in the Pacific makes the isotopic composition heavier. Preservation in the Atlantic during interglacials and in the Pacific during the glacials makes the isotopic composition lighter. The net effect is amplification of glacial-interglacial amplitude in the Atlantic and reduction of the amplitude in the Pacific.

Supported by: NSF grant 77-07732.

DEVELOPMENT AND APPLICATION OF A FIELD  
INSTRUMENTATION SYSTEM FOR THE INVESTI-  
GATION OF SURF ZONE HYDRODYNAMICS

Matthew Noble Greer

Submitted to the Department of Ocean Engineering on February 15, 1979, in partial fulfillment of the requirements for the degree of Oceanographic Engineer and the degree of Master of Science in Ocean Engineering.

Abstract

The development and application of an autonomous field instrumentation system consisting of four current meters and four wave gauges, along with a field monitor and digital recorder, is documented.

The flow sensors are electromagnetic current meters, which employ the principle of electromagnetic induction to sense an induced electrical potential from the flow of water through an imposed magnetic field. The 10 cm diameter, disc-shaped sensor was tested in the laboratory under a wide variety of conditions, including both steady and oscillatory flow tests. The results of these tests indicate an excellent response in terms of linearity and horizontal cosine. The vertical cosine response is close to ideal in the region of  $\pm 30^\circ$ , but beyond a negative angle of attack of approximately  $-30^\circ$  the response is compromised by the onset of separation under dominantly steady flow conditions. The wave gauges are surface-piercing digital sensors, relying on the presence or absence of water at 128 individual sensing electrodes spaced 1.5 cm apart along the front surface of the wave gauge. On command, the instantaneous water surface elevation is measured, then telemetered digitally to the shore-based monitor and recorder.

Field measurements of waves and currents at four stations across the width of the surf zone were made, using this system at a beach along the southern coast of Maine. Spilling breakers (approximately 1.0 m in height with an angle at breaking of about  $8^\circ$ ), translated across the 30 m surf zone, generated an observed net longshore current during the four hour measurement period. The subsequently analyzed data from this experiment showed a strong longshore current which varied across the width of the surf zone, having a maximum of about 15 cm/sec just inside the breaker line. A net offshore current was observed at all four stations, and averaged approximately 10 cm/sec to 15 cm/sec. Using a simplified force balance model for the generation of longshore currents on a plane, uniform beach, the data was further analyzed to investigate the validity and parameterization of the momentum flux forces and bottom friction forces within the surf zone. There was an observed shoreward loss in momentum flux across the width of the surf zone, from about  $-150,000$  dynes/cm outside the breakers to near zero close to the shoreward extent of the surf zone. The computed friction coefficient from the balancing longshore current-induced bottom friction was found to be relatively unstable during period of changing wave and current conditions, but was observed to be between 0.10 and 0.15 during more stable conditions.

Supported by: MIT Sea Grant Program; MIT-WHOI Joint Research Seed Funds; WHOI.

VOLATILE ORGANIC COMPOUNDS IN SEAWATER

Philip M. Gschwend

Submitted to the Woods Hole Oceanographic Institution on January 26, 1979, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Abstract

Vapor phase stripping and solid adsorbent trapping were applied to seawater and related samples to concentrate volatile organic compounds. The concentrates were subsequently analyzed by glass capillar gas chromatography and combined gas chromatography-mass spectrometry. The compound identities and the spatial and temporal distributions of their concentrations were used to determine some sources, transformations, and transport mechanisms of organic matter in the sea.

Volatile organic compounds were determined in seawater samples from the Sargasso Sea, the western Equatorial Atlantic, and the upwelling region off Peru. Pentadecane was present in all three areas in surface samples at 10-40 ng/kg and decreased to 1-2 ng/kg in the deep water. A source related to the transformation of the algal fatty acid, hexadecanoic acid, by zooplankton is proposed since anthropogenic and direct phytoplankton sources are unlikely. C<sub>2</sub>-alkylated benzenes were found in the upwelled water off Peru at about 4 ng/kg in the surface (5 and 20m), 3 ng/kg below the thermocline (100m), and 2 ng/kg or less in deeper water. A surface or atmospheric source is required to produce this distribution. C<sub>6</sub>-C<sub>10</sub> aldehydes were also found in seawater from off Peru. The direct correlation of their concentrations with chlorophyll *a* and with oxygen indicated that they are derived from chemical oxidation of algal metabolites, for example, unsaturated fatty acids. Total volatiles in the oligotrophic Sargasso Sea were about 10-30 ng/kg while the biologically productive upwelling region off Peru contained up to 100 ng/kg.

The temporal variations of volatile organic compound concentrations were investigated in coastal seawater from Vineyard Sound, Massachusetts. Pentadecane and heptadecane showed large summertime concentration increases which were ascribed to benthic algal sources. Laboratory incubations of benthic algal samples supported this conclusion.

The saturated hydrocarbons, from C<sub>13</sub>-C<sub>17</sub>, and alkylated benzenes and naphthalenes were all abundant after an oil spill several miles from the sampling site. C<sub>2</sub>- and C<sub>3</sub>- benzenes were the most persistently abundant volatile compounds and their concentrations were observed to

be 2-10 times higher than average immediately after summer weekends, peak periods of tourist and recreational activities on Cape Cod. Naphthalene and its homologues were more abundant in the winter than in the summer.

C<sub>6</sub>-C<sub>10</sub> aldehydes were observed year-round, but showed a concentration maximum at the time of the late-winter phytoplankton bloom. C<sub>12</sub>-C<sub>15</sub> aldehydes were also found in abundance at that time. Oxidation of algal matter by zooplankton or photochemically-produced oxidizing agents may produce the aldehydes, since laboratory cultures of phytoplankton did not produce these oxygenated volatiles.

An alkene, structurally similar to the known benthic algal gamone, fucoserraten, was also found in Vineyard Sound seawater and in the upwelling region off Peru. Its appearance in Vineyard Sound samples coincided with the period of expected algal reproductive activity in February and March.

Dimethyl polysulfides were found in coastal seawater. They may be produced within the water from precursors such as methyl mercaptan or other known polysulfide metabolites. Total volatile concentrations in Vineyard Sound seawater varied between 200 and 500 ng/kg for the period from January to June. Maximum concentrations occurred during the late-winter phytoplankton bloom and again in the spring from anthropogenic inputs of hydrocarbons.

The highest concentrations of C<sub>2</sub>- and C<sub>3</sub>- benzenes found in Vineyard Sound seawater coincided with motorboat use in the immediate vicinity of the sampling station. The average year-round isomer distribution most closely resembled distributions from gasoline and auto exhaust dissolved in seawater, consistent with an inboard/outboard motorboat source. Atmospheric and runoff delivery of C<sub>2</sub>- and C<sub>3</sub>- benzenes to Vineyard Sound seawater during the period from spring through fall was concluded to be of lesser importance. The atmosphere may serve as a buffer for seawater concentrations of the aromatic compounds, supporting low concentrations in the winter and limiting high concentrations in the summer.

Supported by: ONR contracts N00014-74-C-0262 and 04-8-M01-149; NSF grants OCE 77-08696 and OCE 77-26084.

THE ROLE OF SULFUR IN SALT MARSH METABOLISM

Robert Warren Howarth

Submitted to the Woods Hole Oceanographic Institution-Massachusetts Institute of Technology Joint Program in Biological Oceanography on January 9, 1979, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Abstract

The rate of sulfate reduction in stands of dwarf *Spartina alterniflora* in the Great Sippewissett Salt Marsh is approximately 75 moles  $\text{SO}_4^- \text{m}^2 \text{year}^{-1}$ . This is the highest rate reported for any natural ecosystem. Sulfate reduction is the most important form of respiration in the marsh and results in the annual consumption of  $1800 \text{ g C m}^{-2}$ , approximately equivalent to net primary production. Sulfate reduction rates in the peat are high for at least three reasons: 1) the below-ground production of *Spartina alterniflora* provides a large, annual input of organic substrates over a depth of some 20 cm, 2) sulfate is rapidly resupplied to the peat in infiltrating tidal waters, so low sulfate concentrations never limit the rate of sulfate reduction, and 3) sulfide concentrations remain below toxic levels.

The stable mineral pyrite is a major end-product of sulfate reduction in salt marsh peat while from mono-sulfides are not. This is unlike most anoxic marine sediments and apparently results because iron mono-sulfides are undersaturated. The iron mono-sulfides are undersaturated in part because of the relatively low concentration of total soluble sulfides and in part because of the fairly low pH of the peat. Both of these conditions probably result from the activity of the *Spartina* roots. If the incorporation of  $^{35}\text{S}$  into pyrite were not measured, the  $\text{S}^{35}\text{O}_4^-$  reduction measurements would greatly underestimate the true rate of sulfate reduction.

Pyrite acts largely as a temporary store of reduced sulfur. The pyrite concentration of the peat undergoes seasonal changes. On an annual basis, the reduced sulfur which results from sulfate reduction is either re-oxidized to sulfate within the peat or is exported, much of it as thiosulfate or a similar intermediately reduced compound.

Most of the energy which is originally in organic matters is stored in reduced sulfur compounds when the organic matter is respired by sulfate reducing bacteria. Consequently, the export of reduced sulfur compounds from the peat represents an energy export. The export of energy as reduced inorganic sulfur compounds is

probably larger than the net above-ground production by *Spartina*. This is an important vector for moving some of the energy trapped by the below-ground production of *Spartina* to zones where it is available for coastal food webs.

Supported by: DEB 78-03557.

ALGORITHM FOR COMPUTATION OF THE ACOUSTIC PLANE-WAVE REFLECTION COEFFICIENT OF THE OCEAN BOTTOM

David Richard Martinez

Submitted in June 1979 to the Woods Hole Oceanographic Institution and the Massachusetts Institute of Technology in partial fulfillment of the requirements for the degree of Electrical Engineer and to the Massachusetts Institute of Technology for the degree of Master of Science in Electrical Engineering.

Abstract

For a spherical acoustic wave incident on a horizontally stratified ocean bottom, the reflected pressure field and the plane-wave reflection coefficient are related through a two-dimensional spatial-wavenumber Fourier transform. An algorithm is proposed to evaluate the plane-wave reflection coefficient from the bottom reflected field as a function of angle of incidence.

The algorithm is based on the "Projection-Slice" theorem associated with the two-dimensional Fourier transform. This technique is implemented to evaluate the plane-wave reflection coefficient for a perfectly reflecting ocean bottom and for an isovelocity-low speed ocean bottom model.

Supported by: ONR contract N00014-77-C-0196.

ANALYSIS AND INTERPRETATION OF TIDAL CURRENTS IN THE COASTAL BOUNDARY LAYER

Paul Wesley May

Submitted to the Massachusetts Institute of Technology - Woods Hole Oceanographic Institution Joint Program in Oceanography on May 1, 1979, in partial fulfillment of the requirements for the degree of Doctor of Science.

Abstract

Concern with the impact of human activities on the coastal region of the world's oceans has elicited interest in the so-called "coastal boundary layer" -- that band of water adjacent to the coast where ocean currents adjust to the presence of a boundary. Within this zone,

roughly 10 km wide, several physical processes appear to be important. One of these, the tides, is of particular interest because their deterministic nature allows unusually thorough analysis from short time series, and because they tend to obscure the other processes.

The Coastal Boundary Layer Transect (COBOLT) experiment was conducted within 12 km of the south shore of Long Island, New York, to elucidate the characteristics of the coastal boundary layer in the Middle Atlantic Bight. Analysis of data from this experiment shows that 35% of the kinetic energy of currents averaged over the 30 m depth are due to the semidiurnal and diurnal tides.

The tidal ellipses, show considerable vertical structure. Near-surface tidal ellipses rotate in the clockwise direction for semidiurnal and diurnal tides, while near-bottom ellipses rotate in the counterclockwise direction for the semidiurnal tide. The angle between the major axis of the ellipse and the local coastline decreases downward for semidiurnal and increases downward for diurnal tides. The major axis of the tidal ellipse formed from the depth averaged semidiurnal currents is not parallel to the local shoreline but is oriented at an angle of -15 degrees. This orientation "tilt" is a consequence of the onshore flux of energy which is computed to be about 800 watts/m.

A constant eddy viscosity model with a slippery bottom boundary condition reproduces the main features observed in the vertical structure of both semidiurnal and diurnal tidal ellipses. Another model employing long, rotational, gravity waves (Sverdrup waves) and an absorbing coastline explains the ellipse orientations and onshore energy flux as a consequence of energy dissipation in shallow water. Finally, an analytical model with realistic topography suggests that tidal dissipation may occur very close (2-3 km) to the shore.

Internal tidal oscillations primarily occur at diurnal frequencies in the COBOLT data. Analysis suggests that this energy may be Doppler-shifted to higher frequencies by the mean currents of the coastal region. These motions are trapped to the shore and are almost exclusively first baroclinic mode internal waves.

Supported by: BNL -325-373-S and 359-133-S;  
DOE AC02-79EV10005.

ON THE PROPAGATION OF FREE TOPOGRAPHIC  
ROSSBY WAVES NEAR CONTINENTAL MARGINS

Hsien Wang Ou

Submitted to the Massachusetts Institute of  
Technology - Woods Hole Oceanographic Institution  
Joint Program in Oceanography on April 29, 1979,

in partial fulfillment of the requirements for  
the degree of Doctor of Philosophy.

Abstract

Observational work by Thompson (1977) and others has demonstrated that free topographic waves propagate northward up the continental rise south of New England. To study the dynamical implications of these waves as they approach the shelf, Beardsley, Vermersch, and Brown conducted an experiment in 1976 (called NESS76) in which some moored instruments were strategically placed across the New England continental margin to measure current, temperature, and bottom pressure for about six months.

An analytical model has been constructed to study the propagation of free topographic Rossby waves in an infinite wedge filled with a uniformly stratified fluid. The problem is found after some coordinate transformations to be identical to the corresponding surface gravity wave problem in a homogeneous fluid, but with the roles of the surface and bottom boundaries interchanged. Analytical solutions are thus available for both progressive and trapped waves, forming continuous and discrete spectra in the frequency space. The separation occurs at a nondimensional frequency  $\epsilon = S$ , defined as  $(N/f) \tan \sigma^*$ , where  $N$  and  $f$  are the Brunt-Väisälä and inertial frequencies, and  $\tan \sigma^*$  is the bottom slope. Since an infinite wedge has no intrinsic length scales, the only relevant nondimensional parameters are the frequency  $\epsilon$  and the Burger number  $S$ . Thus, stratification and bottom slope play the same dynamical role, and the analysis is greatly simplified. Asymptotic solutions for the progressive waves have been obtained for both the far field and small  $S$  which enable us to examine the parameter dependence of some of the basic wave properties in the far field, and the spatial evolution of the wave amplitude and phase as they approach the apex when  $S$  is small. The general solution is then presented and discussed in some detail. The eigenfrequencies of the trapped modes decrease when  $S$  decreases and reduce to the short wave limit of Reid's (1958) second class, barotropic edge waves when  $S$  approached zero. The modal structure broadens as  $S$  increases to some critical value above which no such coastally-trapped modes exist.

To simulate more closely the dynamical processes occurring near the continental margin, a numerical model incorporating a more realistic topography than an infinite wedge has been constructed. With stratification imposing an additional barrier, the model suggests that the maximum energy flux transmission coefficient obtained in Kroll and Niiler's barotropic model (1976) is likely an upper bound. Also in the presence of the finite slope changes, the baroclinic fringe waves generated near the slope-

rise junction may form an amphidromic point at some mid-depth and locally reverse the direction of the phase propagation above it. These baroclinic fringe waves also cause an offshore heat flux over the continental rise which, combined with the onshore heat flux generated over the slope region in a frictionless model, induces, across the transect, a mean flow pattern of two counter-rotating gyres with downwelling occurring near the slope-rise junction. Bottom friction always generates an offshore heat flux and therefore modified this mean flow pattern over the slope region. The induced longshore mean flow is approximately geostrophically balanced and generally points to the left facing the shore-line, but its direction can be reversed where the baroclinic fringe waves dominate. The mean thermal wind relation implies a generally denser slope water than that farther offshore.

Some of the model predictions are compared with the data taken from NESS76. The comparisons are generally consistent, suggesting that topographic Rossby wave dynamics may play an important role for the low frequency motions near continental margins.

Supported by: NSF grants OCE-76-01813  
and OCE-78-19513.

THE EVOLUTION OF THE INDIAN OCEAN TRIPLE  
JUNCTION AND THE FINITE ROTATION PROBLEM

Christopher Robert Tapscott

Submitted to the Woods Hole Oceanographic Institution - Massachusetts Institute of Technology Joint Program in Oceanography on February 23, 1979, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Abstract

A major goal in the study of plate tectonics is the acquisition of a knowledge of the history of relative motion among the rigid plates of the earth's lithosphere. The three papers of this thesis contribute to this effort and demonstrate that studies of the stability and evolution of triple junctions and of the finite rotations of systems of three plates can yield significantly more accurate tectonic histories than can studies of the relative motions between two plates alone. Topographic and magnetic investigation of the Southwest Indian Ridge and reconstruction of the plate system of the Indian Ocean shows that both Africa and Antarctica are rigid plates and their pole of relative rotation has remained fixed near 8°N, 42°W since the Eocene. A detailed survey of the Indian Ocean triple junction reveals that the Indian Ocean plate motions have remained constant since 10 Ma. The stability conditions of the junction

show that the general morphology of the Southwest Indian Ridge results from the evolution of the Indian Ocean triple junction. A method is presented for determining the finite rotations best reconstructing the past relative positions of three plates around a triple junction. The method is illustrated by reconstructions of the plates around the Labrador Sea triple junction at the time of anomalies 24 (56 Ma) and 21 (50 Ma). The region of uncertainty of the Greenland-North America finite pole is mapped for each reconstruction, and it demonstrates that consideration of the three plate system yields more well-constrained results than does a treatment of the two plates alone.

Supported by ONR contracts N00014-75-C-0291 and N00014-74-C-0262.

OCEAN BASIN REVERBERATION

John David Zittel

Submitted to the Department of Ocean Engineering on May 11, 1979, in partial fulfillment of the requirements for the degree of Ocean Engineer.

Abstract

Increased use of low-frequency sound in the ocean has led to a desire to understand the effects of the ocean's boundaries on long range sound propagation. Previous experimenters have noted the presence of reverberation for many minutes after the detonation of charges of high explosives in the world's oceans. In the Spring of 1978, the Canada Basin Acoustic Reverberation Experiment (CANBARX) employed an array of hydrophones to measure long-term basin reverberation in the Arctic Ocean. A maximum likelihood estimator was employed to spatially filter (beam form) the CANBARX array data, thus localizing backscatter from specific geographic features. This filtering, in addition to narrow band frequency analysis, allows a significant increase in signal to noise ratio over past experiments. Analyzing at 9 Hz, echoes from specific geographic features have been received for up to 3600 sec after detonation of a charge (typically 440 lb) of high explosive, corresponding to ranges up to 2600 km. Reverberation levels (received level normalized by source level) for eight such experiments are presented. Estimates of transmission path independent boundary scattering strengths are also formed, through the use of a simplified transmission path and boundary interaction model. These estimates are observed to vary with scatterer depth and grazing angle.

Supported by: ONR contract PNDGN00014-77-C-026.

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