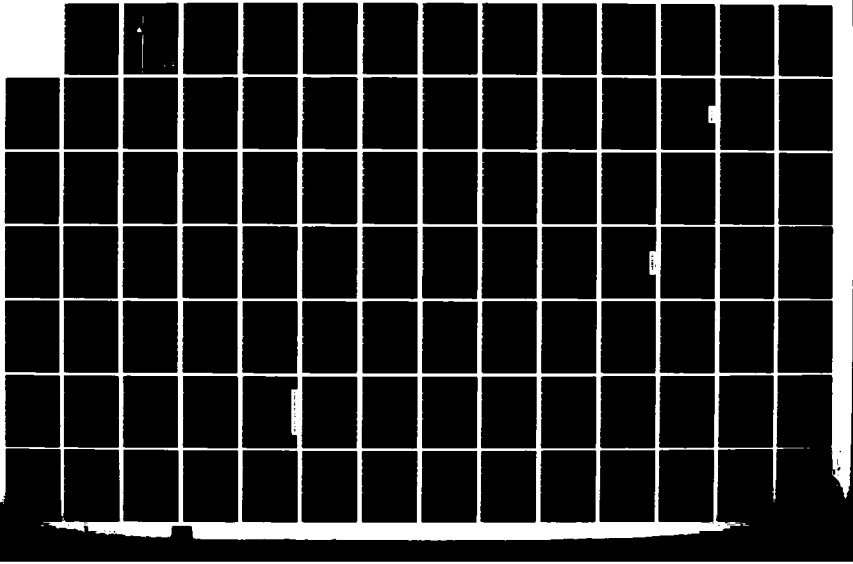
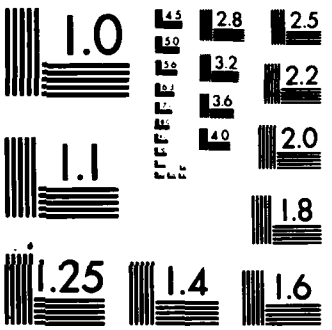
AD-A140 593 ABSTRACTS OF PAPERS SUBMITTED IN 1978 FOR PUBLICATION 1/2
(U)WWOODS HOLE OCAANOGRAPHIC INSTITUTION MA M C THAYER
1978 WHOI-REF-79-37

UNCLASSIFIED F/G 5/2 NL





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

AD-A140 593

DTIC FILE COPY

WHOI-79-37

Woods Hole Oceanographic Institution

REFERENCE NO. 79-37

ABSTRACTS OF PAPERS

SUBMITTED IN 1978 FOR PUBLICATION

APPROVED FOR PUBLIC RELEASE
DISTRIBUTION UNLIMITED

DTIC
ELECTE
APR 27 1984
S D
E

WOODS HOLE, MASSACHUSETTS 02543

84 04 24 177

Reference No. 79-37

ABSTRACTS OF PAPERS

SUBMITTED IN 1978 FOR PUBLICATION

WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts

Editor: Mary C. Thayer

APPROVED FOR DISTRIBUTION

APPROVED FOR PUBLIC RELEASE
DISTRIBUTION UNLIMITED

In citing this manuscript in a bibliography, the reference should be followed by the phrase: UNPUBLISHED MANUSCRIPT

PREFACE

This Summary of Abstracts contains all abstracts submitted for publication during calendar year 1978 by the staff and students of the 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 Because some of the abstracts may not be published in the journal to which they have been submitted initially, we have purposely omitted identifying the journals.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.

For thirteen years similar information was circulated in a different format known as the Summary of Investigations, and during the past four years, it has been distributed as the Summary of Abstracts. Mary Thayer has over these years undertaken the prodigious job of collating this material, editing, and typing it in order to provide the information in a useful and effective manner. In this she has done a superlative job. Mary retires this year after 35 years of service with the Institution, and I would like to dedicate this volume in her honor.

Arthur E. Maxwell

Accession For
NTIS GRA&I [X]
DTIC TAB [ ]
Unannounced [ ]
Justification
By
Distribution/
Availability Codes
Dist | Avail and/or Special
A-1

TABLE OF CONTENTS

Page No.

DEPARTMENT OF BIOLOGY B-1

Aquaculture

Outdoor Algal Mass Cultures. I. Applications B-3
Joel C. Goldman

Outdoor Algal Mass Cultures. II. Photosynthetic Yield Limitations B-3
Joel C. Goldman

Some Aspects of the Growth and Yield of *Gracilaria follifera* in Culture B-3
Brian E. Lapointe and John H. Ryther

The Effect of Temperature on Growth, Physiology and Gametogenesis in the Manila Clam, *Tapes philippinarum* (Adams and Reeve, 1850) B-3
Roger L. Mann

Trace Contaminant Accumulation by Organisms Grown in a Waste Recycling Aquaculture System B-4
Roger L. Mann and John H. Ryther

Opportunities for Virus Transport within Aquatic and Terrestrial Environments . . . B-4
Theorore G. Metcalf, Ronald Comeau, Robert Mooney and John H. Ryther

Biomass Production by Some Marine and Freshwater Plants B-4
John H. Ryther, LaVergne D. Williams, M. Dennis Hanisak, Richard W. Stenberg and Thomas A. DeBusk

Benthos

Zonation and Ecology of Deep-Sea Benthos B-5
Richard L. Haedrich and Gilbert T. Rowe

The Megabenthic Fauna in the Deep Sea South of New England B-5
Richard L. Haedrich, Gilbert T. Rowe and Pamela T. Polloni

Developmental Aberrations Associated with Twinning in Laboratory-Reared Sea Urchin . . B-5
Nancy H. Marcus

The Size-Depth Relationship in Deep Ocean Animals B-6
Pamela T. Polloni, Richard L. Haedrich, Gilbert T. Rowe and C. Hovey Clifford

Spermatophores of Six East North American Pyramidellid Gastropods and their Systematic Significance B-6
Robert Robertson

The Biota and Biological Processes of the Continental Slope B-6
Gilbert T. Rowe and Richard L. Haedrich

Mating Systems in Porcellinoid Isopods: Multiple Paternity and Sperm Mixing in *Porcellio scaber* Latr. B-6
Clay Sassaman

Bioacoustics

A Radio Tag for Big Whales B-7
William A. Watkins

Radio Tagging Report of Finback and Humpback Whales B-7
William A. Watkins, James H. Johnson, Douglas Wartozok

Distinctive Breeding Season Calls of the Harp Seal, *Phoca groenlandica* B-7
William A. Watkins and William E. Schevill

A Radio Whale Tag B-7
William A. Watkins, Douglas Wartzok, Hugh B. Martin III, and Romaine R. Maiefski

A Point for Penetrating Whale Blubber B-7
William A. Watkins

Acoustics and the Behavior of Sperm Whales B-8
William A. Watkins

TABLE OF CONTENTS

Page No.

Fishes

Parasitism and Ecological Relationships among Deep-Sea Benthic Fishes . . . B-8
Ronald A. Campbell, Richard L. Haedrich and Thomas A. Munroe

Baited Camera Lowerings in the Galapagos Rift B-8
Daniel M. Cohen, Richard L. Haedrich and Pamela T. Polloni

Deep-Sea Fish B-8
Richard L. Haedrich

Distribution of Bottom Fishes in the Denmark Strait and Irminger Sea . . . B-8
Richard L. Haedrich and Gerhard Krefft

Experimental Evidence of Geomagnetic Orientation in Elasmobranch Fishes . . . B-9
Adrianus J. Kalmijn

Electric and Magnetic Sensory World of Sharks, Skates, and Rays B-9
Adrianus J. Kalmijn

The Shark's Sixth Sense B-9
Adrianus J. Kalmijn

Microbiology

Deoxyribonucleic Acid Base Composition of Cyanobacteria B-9
Michael Herdman, Monique Janvier, John B. Waterbury, Rosemarie Rippka, Roger Y. Stanier and Manley Mandel

Workshop on Microbial Degradation of Pollutants in Marine Environments . . . B-9
Holger W. Jannasch

Microbial Ecology of Aquatic Low-Nutrient Habitats B-10
Holger W. Jannasch

Microorganisms and Their Aquatic Environment B-10
Holger W. Jannasch

Microbial Turnover of Organic Matter in the Deep Sea B-10
Holger W. Jannasch

Studies on the Microbial Turnover of Organic Substrates in Deep Sea Sediments . B-10
Holger W. Jannasch

The Magnetic Behavior of Mud Bacteria B-10
Adrianus J. Kalmijn

Inactivation of Endotoxin by *Limulus amoebocyte lysate* B-11
Ronald Nachum, Stuart E. Siegel, James D. Sullivan, Jr. and Stanley W. Watson

Genetic Assignments, Strain Histories and Properties of Pure Cultures of Cyanobacteria B-11
Rosemarie R. Rippka, Josette J. Deruelles, John B. Waterbury, Michael Herdman and Roger Y. Stanier

The Effect of Pressure upon the Solubility of Oxygen in Water. Implications of the Deviation from the Ideal Gas Law upon Measurements of Fluorescence Quenching . . B-11
Craig D. Taylor

Solubility of Oxygen in a Seawater Medium which is in Equilibrium with a High Pressure Oxy-Helium Atmosphere B-11
Craig D. Taylor

Growth of a Bacterium under a High Pressure Oxy-Helium Atmosphere B-11
Craig D. Taylor

Microbial Dark Assimilation of CO_2 in the Cariaco Trench B-12
Jon H. Tuttle and Holger W. Jannasch

Quantitative Method for Determining Less than a pg/ml of LPS. B-12
Frederica W. Valois

Widespread Occurrence of a Unicellular, Marine, Planktonic Cyanobacterium . . B-12
John B. Waterbury, Stanley W. Watson, Robert R.L.Guillard and Larry Brand

TABLE OF CONTENTS

Page No.

Patterns of Growth and Development in Pleurocapsalean cyanobacteria . . . B-12
John B. Waterbury and Roger Y. Stanier

Developmental Patterns of Pleurocapsalean cyanobacteria (in Development and Morphogenesis in Prokaryotes. J.H.Parish, ed.). B-12
John B. Waterbury

Physiological and Morphological Observations on Thiovulum sp. B-12
Carl O. Wirsen and Holger W. Jannasch

PHYSIOLOGY

Effects of Low Levels of Hydrocarbons on Embryonic, Larval and Adult Winter Flounder *(Pseudopleuronectes americanus)* B-13
Walter W. Kuhnhold, Diane Everich, John J. Stegeman, James Lake and Richard E. Wolke

Factors Involved in Herbivore Food Preference B-13
Mary E. Nicotri

High Benzo(a)pyrene Hydroxylase Activity in the Marine Teleost Fish *Stenotomus versicolor* B-13
John J. Stegeman and Robert Binder

Hepatic and Extrahepatic Microsomal Electron Transport Components and Mixed-Function Oxygenases in the Marine Fish *Stenotomus versicolor* B-14
John J. Stegeman, Robert L. Binder and Ann M. Orren

Bioactivation of Polynuclear Aromatic Hydrocarbons to Cytotoxic and Mutagenic Products by Marine Fish B-14
John J. Stegeman, Thomas R. Skopek and William G. Thilly

In vitro Metabolism of Polynuclear Aromatic Hydrocarbons in Deep-Sea Fishes . . B-14
John J. Stegeman

PHYTOPLANKTON

The Role of Chelators and Trace Metals in Toxic Dinoflagellate Blooms . . B-14
Donald M. Anderson and Michael Corbett

Toxic Dinoflagellate Blooms in the Cape Cod Region of Massachusetts . . . B-15
Donald M. Anderson and Francois M.M.Morel

Growth Limitation of a Coastal Diatom by Low Zinc Ion Activity B-15
Michael Anderson, Francois M.M.Morel and Robert R.L.Guillard

Recovery Potential of Phytoplankton after Passage through Coastal Power Plant Entrainments. B-15
Joel C. Goldman and Helen L. Quinby

Chlorine Disappearance in Seawater B-15
Joel C. Goldman, Helen L. Quinby and Judith M. Capuzzo

Biological and Geochemical Influences on Nutrient Cycling in Oceanic Waters . . B-16
Joel C. Goldman, James J. McCarthy and Dwight G. Peavey

Temperature Effects on Steady State Growth, Phosphorus Uptake, and the Chemical Composition of a Marine Phytoplankter B-16
Joel C. Goldman

Hydrogen Formation by Marine Algae B-16
Elias Greenbaum, David Mauzerall, and Robert R.L.Guillard

An Asymmetric Formulation of the Distribution Characteristics of Phytoplankton Species: An Investigation in Interpretation B-16
Edward M. Hulburt

'Place' in Ecology B-17
Edward M. Hulburt

TABLE OF CONTENTS

Page No.

A Referential Context for Description of Phytoplankton and Nutrients in New York Waters. B-17
Edward M. Hulburt and Nathaniel Corwin

Attributes of the Plankton Flora at Bushehr, Iran B-17
Edward M. Hulburt, Farideh Mahmoodian, Mary Russell, Firuzeh Stalcup, Shahla Lalezary and Parviz Amirhor

Aquil: A Chemically Defined Phytoplankton Culture Medium for Trace Metal Studies . B-18
Francois M.M.Morel, John G. Rueter, Donald M. Anderson and Robert R.L.Guillard

Distribution of Electromorphs and Growth-rate Characteristics in Isolates of *Thalassiosira pseudonana* from the Neritic-Oceanic Boundary B-18
Lynda S. Murphy, Robert R.L.Guillard, Hsueh-tze Lee and Larry E. Brand

The Effects of Industrial Waste on Marine Phytoplankton at Deep-Water Dumpsite 106 . B-18
Lynda S. Murphy, Peter H. Hoar and Rebecca A. Belastock

Biochemical Taxonomy of Marine Phytoplankton by Electrophoresis of Enzymes. II. Loss of Heterozyogosity in Clonal Cultures of the Centric Diatoms *Skeletonema costatum* and *Thalassiosira pseudonana* B-18
Lynda S. Murphy

Nitrogenous Nutrition of Marine Phytoplankton in Nutrient Depleted Waters . . B-19
James J. McCarthy and Joel C. Goldman

Periodicity of Cell Division in 26 Planktonic Marine Algae Grown on Light-Dark Cycles B-19
David M. Nelson and Larry E. Brand

The Importance of Silicon in Marine Eutrophication B-19
Charles B. Officer and John H. Ryther

Harvest of Marine Microalgae by Centrifugation in Density Gradients of "Percoll", a Modified Silica Sol. IN: Methodological Surveys in Biochemistry B-19
Ellen M. Reardon, Carl A. Price and Robert R.L.Guillard

Tidal Resuspension in Buzzards Bay, Massachusetts. I. Seasonal Changes in the Resuspension of Organic Carbon and Chlorophyll a. B-19
Michael R. Roman and Kenneth R. Tenore

Tidal Resuspension in Buzzards Bay, Massachusetts. II. Seasonal Changes in the Size Distribution of Chlorophyll, Particle Concentration, Carbon and Nitrogen in Resuspended Particulate Matter B-20
Michael R. Roman

Salt Marshes

Heavy Metal Uptake in a New England Salt Marsh B-20
Ann Giblin, Alain Bours, Ivan Valiela and John M. Teal

The Environmental Impact of Industrial Energy Systems in the Coastal Zone . . B-20
Charles A.S.Hall, Robert Howarth, Berrien Moore III, and Charles J. Voresmarty

A No. 2 Fuel Oil Spill in Bourne, Massachusetts: The Immediate Assessment of the Effects on Marine Invertebrates and a Three-Year Study of Growth and Recovery of a Salt Marsh B-20
George R. Hampson and Edwin T. Moul

The Rapid Formation of Pyrite in a Salt Marsh and its Importance to Ecosystem Metabolism B-21
Robert W. Howarth

Denitrification in a Salt Marsh Ecosystem B-21
Warren Kaplan, Ivan Valiela and John M. Teal

Nitrogen Fixation by Rhizosphere and Free-living Bacteria in Salt Marsh Sediments B-21
John M. Teal, Ivan Valiela, Diane Berlo

Enrichment in Coastal Wetlands B-21
John M. Teal and Ivan Valiela

TABLE OF CONTENTS

Page No.

WATER RESOURCES AND RENOVATION

The Water Table of Cape Cod B-22
Alfred C. Redfield

Wastewater Renovation and Retrieval on Cape Cod B-22
Ralph F. Vaccaro, Peter E. Kallio, Bostwick H. Ketchum, William B. Kerfoot, Alicja Mann, Patricia L. Deese, Carl Palmer, Mark R. Dennett, Paul C. Bowker, Nathaniel Corwin and Steven Manganini

ZOOPLANKTON

The Effects of Halogen Toxicants on Survival, Feeding and Egg Production of the Rotifer *Brachionus plicatilis* B-22
Judith M. Capuzzo

Tidally-Generated Internal Wave Packets in Massachusetts Bay, U.S.A.: Preliminary Physical and Biological Results B-23
Loren R. Haury, Melbourne G. Briscoe, Marshall H. Orr

Plankton and Internal Waves: The Massachusetts Bay Experiment B-23
Loren R. Haury, Melbourne G. Briscoe and Marshall H. Orr

The Effect of Temperature on the Toxicity of Chlorinated Cooling Waters to Marine Animals - a Preliminary Review B-23
Judith M. Capuzzo

Larval Development in the American Lobster: Changes in Metabolic Activity and the O:N Ratio B-23
Judith M. Capuzzo and Bruce A. Lancaster

Some Physiological and Biochemical Considerations of Larval Development in the American Lobster, *Homarus americanus* B-24
Judith M. Capuzzo and Bruce A. Lancaster

The Effects of Dietary Carbohydrate Levels on Protein Utilization in the American Lobster, *(Homarus americanus)* B-24
Judith M. Capuzzo and Bruce A. Lancaster

Origins of Oceanic Plankton in the Middle Atlantic Bight B-24
James Cox and Peter H. Wiebe

Macrozooplankton and its Environment B-25
Richard L. Haedrich and David C. Judkins

The Filter-feeding Rates and Particle Reteneion Efficiencies of Three Species of Cyclosalpa (Tunicata, Thalicea). B-25
G. Richard Harbison and Vicki McAlister

Effects of Temperature on the Swimming of Salps (Tunicata, Thaliacea) Implications for Vertical Migration B-25
G. Richard Harbison and Robert B. Campenot

Experimental Evaluation of the Escape Reaction of *Calanus finmarchicus* . . . B-26
Loren R. Haury, Douglas E. Kenyon and James R. Brooks

Relationships Between Oceanic Epizooplankton Distributions and the Seasonal Deep Chlorophyll Maximum in the Northwestern Atlantic Ocean B-26
Peter B. Ortner and Peter H. Wiebe

TABLE OF CONTENTS

Page No.

DEPARTMENT OF CHEMISTRY C-1

Organic and Biological Chemistry

Volatile Organic Compounds in Coastal Seawater: Preliminary Results . . . C-3
Rene P. Schwarzenbach, Richard H. Bromund, Philip M. Gschwend and Oliver C. Zafiriou

Sterol Geochemistry of Sediments from the Western North Atlantic Ocean and Adjacent Coastal Areas C-3
Cynthia L. Lee, John W. Farrington and Robert B. Gagosian

C_1-C_5 Hydrocarbons from Core Gas Pockets - IPOD Legs 56 and 57 . . . . . C-3
Jean K. Whelan and Shunji Sato

Dissolved Gases in Black Sea Sediments C-3
John M. Hunt and Jean K. Whelan

C_1-C_7 Hydrocarbons in Holes 379A, 380/380A, and 381 . . . . . C-4
Jean K. Whelan and John M. Hunt

Volatile Organic Compounds in Quaternary Sediments C-4
John M. Hunt and Jean K. Whelan

Light Hydrocarbons in Sediments of DSDP Leg 44 Holes C-4
John M. Hunt and Jean K. Whelan

Characterization of Bitumens and Coals C-4
John M. Hunt

Organic Sediments C-4
John M. Hunt

Processes Controlling the Distribution of Biogenic Organic Compounds in Seawater . . C-5
Robert B. Gagosian and Cynthia L. Lee

Steroid Ketones in Surface Sediments from the Southwest African Shelf C-5
Robert B. Gagosian and Steven O. Smith

The Transport and Budget of Sterols in the Western North Atlantic Ocean . . . C-5
Robert B. Gagosian and Gale E. Nigrelli

A Versatile Interchangeable Chamber Seawater Sampler C-6
Robert B. Gagosian, Jerome P. Dean, Jr., Robert Hamblin and Oliver C. Zafiriou

Sterenes in Surface Sediments from the Southwest African Shelf and Slope . . . C-6
Robert B. Gagosian and John W. Farrington

Meeting Report: Future Research Problems in Marine Organic Chemistry C-6
Robert B. Gagosian, Saiyed I. Ahmed, John W. Farrington, Richard F. Lee, Richard F.C.Mantoura, Kenneth H. Nealson, Theodore T. Packard and Kenneth L. Reinhart, Jr.

Sterol Composition of *Ciona intestinalis* C-6
Kishan C. Gupta, Richard L. Miller, John R. Williams, Robert B. Gagosian and Franz Heinzer

Stenols and Stanols in the Oxic and Anoxic Waters of the Black Sea C-6
Robert B. Gagosian and Franz Heinzer

Animo Acids in Interstitial Waters of Marine Sediments C-7
Susan M. Henrichs and John W. Farrington

The Rates of Transport and Fates of Petroleum Hydrocarbons in a Controlled Marine Ecosystem and a Note on Analytical Variability C-7
Juanita N. Gearing, Patrick J. Gearing, Terry Wade, James G. Quinn, Harry B. McCarty, John W. Farrington and Richard F. Lee

The Mussel Watch C-7
Edward D. Goldberg, Vaughan T. Bowen, John W. Farrington, George Harvey, John H. Martin, Patrick L. Parker, Robert W. Risebrough, William Robertson, Eric Schneider and Eric Gamble

Analyses of Aromatic Hydrocarbons in Intertidal Sediments Resulting from Two Spills of No.2 Fuel Oil in Buzzards Bay, Massachusetts C-8
John M. Teal, Kathryn Burns and John W. Farrington

TABLE OF CONTENTS

Page No.

Geochemistry

An Evaluation of the Behavior of the Rare Earth Elements during the Weathering of Sea-Floor Basalt C-9
John N. Ludden and Geoffrey Thompson

The Origin of Lavas from the 90°E Ridge Eastern Indian Ocean: An Evaluation of Fractional Crystallization Models C-9
John N. Ludden, Geoffrey Thompson, Wilfred B. Bryan and Frederick A. Frey

Optical Emission Spectrometer/Spectrograph for Major and Minor Oxide and Trace Element Analysis of Silicate Rocks C-9
Donald C. Bankston, Susan E. Humphris and Geoffrey Thompson

Trace Element Analyses of Allende Meteorite Reference Sample C-10
Geoffrey Thompson

Geological and Geophysical Investigation of the Mid-Cayman Rise Spreading Center: Initial Results and Observations C-10
Robert D. Ballard, Wilfred B. Bryan, Karleen Davis, Jelle deBoer, Steve DeLong, Henry J.B.Dick, Kenneth O. Emery, Paul J. Fox, Mark Hempton, Freida Malcolm, William G. Melson, Randall Spydell, Janet Stroup, Geoffrey Thompson, Raymond Wright and Elazar Uchupi

The Behavior of the Rare Earth Elements during Submarine Weathering of Tholeiitic Basalt C-10
John N. Ludden and Geoffrey Thompson

Very Low Temperature Hydrothermal Alteration of the Oceanic Crust and the Problem of Fluxes of Potassium and Magnesium C-10
Thomas W. Donnelly, Geoffrey Thompson and Paul T. Robinson

The Chemistry of Altered Basalts at Site 417A, DSDP Leg 51 . . . . . C-11
Thomas W. Donnelly, Geoffrey Thompson and Matthew Salisbury

Petrologic Character of the Atlantic Crust from DSDP and IPOD Drill Sites . . . C-11
Wilfred B. Bryan, Geoffrey Thompson and Frederick A. Frey

DC Plasma Emission Spectrometry for Element Determinations in Igneous Rocks . . C-12
Donald C. Bankston, Susan E. Humphris and Geoffrey Thompson

The Nature and Petrogenesis of Intra-Oceanic Plate Alkaline Eruptive and Plutonic Rocks: King's Trough, Northeast Atlantic C-12
Jonathan Stebbins and Geoffrey Thompson

Chemical Variation in Glass-Whole Rock Pairs from Individual Cooling Units in Holes 417D and 418A C-12
Hubert Staudigel, Wilfred B. Bryan and Geoffrey Thompson

Tholeiitic and Alkali Basalts from the Mid-Atlantic Ridge at 43°N C-12
Twugio Shibata, Geoffrey Thompson and Frederick A. Frey

Cation Exchange Characteristics of Amazon River Sediment and its Reaction with Seawater C-13
Frederick L. Sayles and Paul C. Mangelsdorf, Jr.

The Composition and Diagenesis of Interstitial Solutions: I. Fluxes Across the Seawater-Sediment Interface in the Atlantic Ocean C-13
Frederick L. Sayles

Chemistry and Mineralogy of Spilites from the Ocean Floor: Effect of Seawater/Basalt Ratio C-13
William E. Seyfried, Jr., Michael J. Mottl and James L. Bischoff

Chemical Exchange during Hydrothermal Alteration of Basalt by Seawater - I. Experimental Results for Major and Minor Components of Seawater C-14
Michael J. Mottl and Heinrich D. Holland

Chemical Exchange during Hydrothermal Alteration of Basalt by Seawater - II. Experimental Results for Fe, Mn, and Sulfur Species C-14
Michael J. Mottl, Heinrich D Holland and Rosamund F. Carr

TABLE OF CONTENTS

Page No.

Sub-Sea-Floor Hydrothermal Systems: Rock- vs. Seawater-Dominated C-15
Michael J. Mottl and William E. Seyfried

Seawater Chemistry

Nitrite Photolysis in Seawater by Sunlight C-15
Oliver C. Zafiriou and Mary B. True

Nitrite Photolysis as a Source of Free Radicals in Productive Surface Waters . . C-15
Oliver C. Zafiriou and Mary B. True

Nitrate Photolysis in Seawater by Sunlight C-16
Oliver C. Zafiriou and Mary B. True

Exploratory Analyses of Trichlorofluoromethane (F-11) in North Atlantic Water Columns C-16
Paul M. Hammer, James M. Hayes, William J. Jenkins and Robert B. Gagosian

Stable-Isotope Paleoclimatology: A Possible Measure of Past Seasonal Contrast from Foraminiferal Tests C-17
Werner G. Deuser

O^{18} and C^{13} Contents of Carbonates from Deep Sea Drilling Sites in the Black Sea . C-17
Werner G. Deuser, Egon T. Degens and Peter Stoffers

Oceanic Residence Times of the Elements C-17
Werner G. Deuser

Marine Biota, Nearshore Sediments, and the Global Carbon Balance C-17
Werner G. Deuser

Chemical Oceanographic Data from the Persian Gulf and Gulf of Oman C-18
Peter G. Brewer, Alan P. Fleer, Susan Kadar, Deborah K. Shafer and Clarence L. Smith

Consumption of Dissolved Methane in the Deep Ocean C-18
Mary I. Scranton and Peter G. Brewer

Direct Observation of the Oceanic CO_2 Increase C-18
Peter C. Brewer

Oceanic Elemental Scavenging C-18
Wei Min Hao and Peter G. Brewer

Radiochemistry

Soluble and Particle-associated fallout Radionuclides in Mediterranean Water and Sediments C-19
Hugh D. Livingston, Susan A. Casso, Vaughan T. Bowen and John C. Burke

Pu and ^{137}Ca in Coastal Sediments C-19
Hugh D. Livingston and Vaughan T. Bowen

Fallout Radionuclides in Mediterranean Sediments C-19
Hugh D. Livingston, Vaughan T. Bowen and John C. Burke

A Mass Balance for ^{137}Cs and ^{90}Sr in the North Atlantic Ocean C-20
Stuart L. Kupferman and Hugh D. Livingston

A Procedure for Independently Estimating Blanks and Uncertainties for Measured Values of ^{90}Sr and ^{137}Cs Concentrations in the Atlantic Ocean C-20
Stuart L. Kupferman and Hugh D. Livingston

The Tritium-Helium-3 Method in Hydrology C-20
Thomas Torgersen, W. Bryan Clarke and William J. Jenkins

On the Terrestrial Budgets of Helium and Argon Isotopes and the Degassing of the Earth C-20
William J. Jenkins

Radionuclide Ratios in Wet and Dry Deposition Samples from June 1976 through December 1977 . . . . . C-21
Muralidhara B. Gavini

Radioactive Fallout at Woods Hole, Massachusetts C-21
Muralidhara B. Gavini

TABLE OF CONTENTS

Page No.

Natural Matrix Standard C-21
Vaughan T. Bowen

Bacteria and Plutonium in Marine Environments C-21
Anne E. Carey and Vaughan T. Bowen

Lead-210 and Polonium-210 as Marine Geochemical Tracers: A Review and a Discussion of Some Recent Results from the Labrador Sea C-22
Michael P. Bacon, Derek W. Spencer and Peter G. Brewer

TABLE OF CONTENTS

Page No.

DEPARTMENT OF GEOLOGY AND GEOPHYSICS GG-1

Geology

Chemical Variation in Glass-Whole Rock Pairs from Individual Cooling Units in Holes 417D and 418A GG-3
Hubert Staudigel, Wilfred B. Bryan and Geoffrey Thompson

DSDP Sites 417 and 418: A Petrogentic Synthesis GG-3
Martin F.J. Flower and Wilfred B. Bryan

Site 418 Basalt Chemistry and Magmatic Variation GG-4
Martin F.J. Flower and Wilfred B. Bryan

Low K_2O Dacite, Tonga-Kermadec Ridge GG-4
Wilfred B. Bryan

Hypsometry of the Continental Shelf off Eastern North America GG-4
Kenneth O. Emery

General Implications of the Leg 49 Drilling Program on North Atlantic Ocean Geology . GG-4
Bruce P. Luyendyk, Alexander Shor, and Joseph R. Cann

Bottom Currents and Ice Rafting in the North Atlantic: Interpretation of Neogene Depositional Environments of Leg 49 Cores GG-5
Alexander N. Shor and Richard Z. Poore

The Red Sea - The Oceanography of a Semi-enclosed Sea GG-5
David A. Ross

The Stratigraphy and Structure of the Laurentian Cone Region GG-5
Elazar Uchupi, James A. Austin, and David A. Ross

Compositional Layering in Alpine Peridotites: Evidence for Pressure Solution Creep in the Mantle GG-6
Henry Dick and John Sinton

Disruption of the Feni Sediment Drift by Debris Flows and Associated Turbidity Currents from Rockall Bank GG-6
Roger D. Flood, Charles D. Hollister, and Peter Lonsdale

Morphology of Seamounts in the Western Pacific and Philippine Basin from Multi-Beam Sonar Data GG-6
Charles D. Hollister, Morris F. Glenn, and Peter F. Lonsdale

Off-Ridge Volcanism and Seafloor Spreading in the Shikoku Basin GG-7
George Klein, Henry J.B. Dick, *et al.*

Plastering and Decorating in the North Atlantic GG-7
Charles D. Hollister, Roger Flood, and Ian Nicholas McCave

Particulate Calcium Carbonate in New England Shelf Waters: Result of Shell Degradation and Resuspension GG-7
Michael G. Fitzgerald, Carol M. Parmenter and John D. Milliman

Morphology and Structure of the Upper Amazon Continental Margin GG-7
John D. Milliman

Compositional Variation in a Steady-State Zoned Magma Chamber: Mid-Atlantic Ridge at 36°50'N GG-8
Wilfred B. Bryan and Geoffrey Thompson

Structure and Origin of Three Continental Margin Plateaus, Northeastern Brazil . . GG-8
Roberto Fainstein and John D. Milliman

The Geologic History of the Passive Margin off New England and the Canadian Maritime Provinces GG-8
Elazar Uchupi and James Austin, Jr.

Site 417 Basalt Chemistry and Magmatic Variation GG-9
Wilfred B. Bryan and Martin F.J. Flower

TABLE OF CONTENTS

Page No.

Relic Oysters on the United States Atlantic Continental Shelf: A Reconsideration of Their Usefulness in Understanding Late Quaternary Sea-Level History: A Discussion. GG-9
Kenneth O. Emery and Arthur S. Merrill

Regional Variation and Petrogenesis of Basalt Glasses from the FAMOUS Area, Mid-Atlantic Ridge GG-9
Wilfred B. Bryan

The Origin of Lavas from the 90°E Ridge, Eastern Indian Ocean: An Evaluation of Fractional Crystallization Models GG-9
John N. Ludden, Geoffrey Thompson, Wilfred B. Bryan and Frederick A. Frey

Basalts and Related Rocks from Deep-Sea Drilling Sites in the Central and Eastern Indian Ocean GG-10
Geoffrey Thompson, Wilfred B. Bryan, Frederick A. Frey and John S. Dickey, Jr.

Petrologic Character of the Atlantic Crust from DSDP and IPOD Drill Sites . . GG-10
Wilfred B. Bryan, Geoffrey Thompson and Frederick Frey

Active Deep Sea Sedimentary Furrows GG-11
Roger D. Flood and Charles D. Hollister

Cruise Data Report, R/V *ATLANTIS II* 93 Leg 7 . . . . . GG-11
Robert C. Groman and James A. Dunworth

Deep Thermocline Flow and Current-Controlled Sedimentation in the Amirante Passage, Western Indian Ocean GG-11
David A. Johnson and John E. Damuth

Geophysics

Marine Magnetic Anomalies, Geomagnetic Field Reversals, and Motions of the Ocean Floor and Continents GG-12
James Heirtzler

Relative Rates of Movement of the Ocean Crust GG-12
James Heirtzler

The Argo Abyssal Plain GG-12
James R. Heirtzler, Peter Cameron, Peter J. Cook, Thomas Powell, Hans A. Roeser, Sutesna Sukardi and John J. Veevers

Deep-Ocean Drilling GG-12
James R. Heirtzler and Arthur Maxwell

The Kane Fracture Zone in the Central Atlantic Ocean GG-13
Graham M. Purdy, Philip D. Rabinowitz and Jan J.A. Velterop

An Ocean Bottom Hydrophone Instrument for Seismic Refraction Experiments in the Deep Ocean GG-13
Donald E. Koelsch and Graham M. Purdy

Interpolation of Unit Vectors GG-13
Robert Parker and Charles Denham

The Oblique Intersection of the Mid-Atlantic Ridge with Charlie-Gibbs Transform Fault. GG-13
Peter Lonsdale and Alexander Shor

A Deep-Towed Hydrophone Seismic Reflection Survey around IPOD Sites 417 and 418 . GG-14
Graham M. Purdy, John I. Ewing and George M. Bryan

Modeling the Oceanic Magnetic Source Layer GG-14
Hans Schouten and Charles R. Denham

On the Likelihood of Mixed Polarity in Oceanic Basement Drill Cores . . . GG-14
Charles R. Denham and Hans Schouten

Tectonics of the Western Gulf of Oman GG-14
Robert S. White and David A. Ross

Multi-Beam Sonar Data from the Abyssal Western Pacific and Philippine Basin . . GG-14
Morris F. Glenn and Charles D. Hollister

TABLE OF CONTENTS

Page No.

A Geophysical Survey within the Mesozoic Magnetic Anomaly Sequence South of Bermuda GG-15
Graham M. Purdy and Kristin Rohr

A Near-Bottom Traverse of Rockall Trough: Hydrographic and Geologic Inferences GG-15
Peter Lonsdale and Charles D. Hollister

Acoustic Stratigraphy and Structure of the Oceanic Crust GG-15
John Ewing and Robert Houtz

An Analysis of Isostasy in the World's Oceans: Part 3 - Aseismic Ridges . . GG-16
Robert S. Detrick and Anthony B. Watts

Multi-Beam Sonar Study of the Mid-Atlantic Ridge Rift Valley GG-16
Joseph D. Phillips and Henry S. Fleming

Geological and Geophysical Investigation of the Mid-Cayman Rise Spreading Center: Initial Results and Observations GG-16
Robert Ballard, Wilfred Bryan, Henry Dick, Kenneth O. Emery, Geoffrey Thompson, Elazar Uchupi *et al.*

The North Atlantic Ridge: Observational Evidence for its Generation and Aging . GG-17
James R. Heirtzler

Seismic Refraction and Reflection Studies in the Timor-Aru Trough System and Australian Continental Shelf GG-18
Randall S. Jacobson, George G. Shor, Jr., R.M.Kieckhefer and Graham M. Purdy

Paleontology/Sedimentology

Salt Diffusion in Eastern Mediterranean Sea Sediments GG-18
Henry Elderfield and Colin P. Summerhayes

Late Pleistocene and Holocene Sedimentation in the Persian Gulf - Gulf of Oman . GG-18
Peter Stoffers and David A. Ross

The Latitudinal and Bathymetric Ranges of Living and Fossil *Mesodesma arctatum* (Bivalvia) with Notes on Habits and Habitat Requirements GG-19
Arthur S. Merrill, John D. Davis, and Kenneth O. Emery

Lowest Tertiary Biostratigraphy and Tectonics of Northeastern Libya . . . GG-19
Frank T. Bart and William A. Berggren

Relationship between the Dissolution Rates and the Chemistry of the Deep Ocean Water in the North Atlantic GG-19
Taro Takahashi and Susumu Honjo

Paleogene Benthonic Foraminiferal Biostratigraphy and Bathymetry of the Central Ranges of California GG-20
William A. Berggren and Jane Aubert

Quantitative Paleobathymetry and Paleoecology of the Late Pliocene-Early Pleistocene Foraminifera of Le Castella (Calabria, Italy) GG-20
Mary L. Bremer, Madeleine Briskin and William A. Berggren

Sedimentation in the Fraser River and its Estuary, Southwestern British Columbia (Canada) GG-21
John D. Milliman

Late Cenozoic Sedimentation and Erosion on the Rio Grande Rise GG-21
David A. Johnson and Christopher S. Peters

Late Neogene Calcareous Plankton Biochronology of the Rio Grande Rise (South Atlantic Ocean) GG-22
Bilal U. Haq and William A. Berggren

Early Cenozoic Calcareous Nannoplankton Biostratigraphy and Paleobiogeography of North Africa and the Middle East and Trans-Tethyan Correlations GG-22
Bilal U. Haq and Marie-Pierre Aubry

Late Pliocene-Pleistocene Calcareous Plankton Stratigraphy of the Rio Grande Rise GG-22
Christopher S. Peters

TABLE OF CONTENTS

Page No.

The Sediments of the Argo Abyssal Plain and Adjacent Areas, Northeast Indian Ocean GG-23
Peter J. Cook, John J. Veevers, James R. Heirtzler and Peter J. Cameron

Deep Thermocline Flow and Current-Controlled Sedimentation in the Amirante Passage, Western Indian Ocean GG-23
David A. Johnson and John E. Damuth

Sedimentary Fabric: A Tool to Delineate a High-Velocity Zone within a Deep Western Indian Ocean Bottom-Current GG-24
Brooks B. Ellwood, Michael T. Ledbetter and David A. Johnson

Marine Resources

A Review of Oceanography and Limnology in Israel GG-24
Kenneth O. Emery

Exports of Nations GG-24
Kenneth O. Emery and Rufus D. Catchings

Marine Mineral Resources and Uniformitarianism GG-24
Kenneth O. Emery

Resources of the Deep Sea other than Manganese Nodules GG-25
David A. Ross

TABLE OF CONTENTS

Page No.

DEPARTMENT OF OCEAN ENGINEERING OE-1

Acoustics

Ray Calculations of Ocean Sound Channels using a Pocket Programmable Calculator and Extended forms of the Hirsch-Carter Mathematical Model with Tables of the Incomplete Beta Function OE-3
Lincoln Baxter II

Comparison of High-Resolution Normal-Incidence 3.5 kHz and 12 kHz Reflections with Geotechnical Properties of Giant Piston Cores OE-3
Willard Dow and Charles D. Hollister

Amplitude Fluctuations of Acoustic Signals Received from CW Sources Towed in the Deep Ocean (U) OE-3
Kenneth D. Flowers, Dan J. Ramsdale, George V. Frisk and George R. Giellis

Inhomogeneous Waves and the Plane Wave Reflection Coefficient OE-4
George V. Frisk

A Technique for the Evaluation of Circularly Symmetric Two-Dimensional Fourier Transforms and its Application to the Measurement of Ocean Bottom Reflection Coefficients OE-4
Alan V. Oppenheim, George V. Frisk and David R. Martinez

Acoustic Monitoring of the Dispersion Characteristics of the Particulate Phase of Industrial Chemical Waste at Deep Water Dump Site 106 . . . . . OE-4
Marshall H. Orr and Frederick R. Hess

Remote Acoustic Sensing of the Particulate Phase of Industrial Chemical Wastes and Sewage Sludge OE-4
Marshall H. Orr

Remote Sensing of Near Surface Oceanic Mixing Processes OE-5
Frederick R. Hess and Marshall H. Orr

Remote Sensing of Internal Waves, Isopycnal Surfaces, and Interleaving Water Masses in the Vicinity of Hudson Canyon OE-5
Marshall H. Orr and Frederick R. Hess

Remote Sensing of Physical Processes in the Ocean using High Frequency Acoustic Backscattering Systems OE-5
Marshall H. Orr and Frederick R. Hess

Acoustic Phase Tracking of Ocean Moorings OE-5
Robert C. Spindel, Robert P. Porter and John A. Schwoerer

Statistics of Low-Frequency Multipath Fluctuations in the Ocean OE-6
Robert P. Porter and Robert C. Spindel

Geology

The Galapagos Rift at 86°W, 3. Sheet Flows, Collapse Pits and Lava Lakes of the Rift Valley OE-6
Robert D. Ballard, Robin T. Holcomb and Tjeerd H. van Andel

Recent Geology of the Chotts of Tunisia OE-6
James W. Mavor, Jr.

Instrumentation

The Sea-Data 651-4 Data Logger OE-7
David S. Hosom and Bradford Butman

A Systems Approach to Underwater Camera Data Correlation and Interpretation . . OE-7
Gary G. Hayward, William D. McElroy, Jr., David S. Hosom and William M. Marquet

A Transmissometer-Nephelometer and Calibration Facility OE-7
David S. Hosom and Bradford Butman

Prewired Encapsulated Strain Gages for Hard-to-Reach Locations OE-7
Arnold G. Sharp

TABLE OF CONTENTS

Page No.

Use of Industry Standards for Shipboard Data Systems 0E-7
Kenneth R. Peal and Albert M. Bradley

Design of a Stable Floating Platform for Air-Sea Interaction Measurements . . 0E-7
Henri O. Berteaux and Robert G. Walden

A Microprocessor Acoustic Data Buoy 0E-8
Robert C. Spindel, Kenneth R. Peal and Donald E. Koelsch

Ocean Dynamics

Combined Wave and Current Interaction with a Rough Bottom 0E-8
William D. Grant and Ole Secher Madsen

Refractive Microstructure from Diffusive and Turbulent Ocean Mixing . . . 0E-9
Albert J. Williams 3rd

The Role of Double Diffusion in a Gulf Stream Frontal Intrusion 0E-9
Albert J. Williams 3rd

Statistics

Confidence Intervals for Similarity Measures using the Two Sample Jackknife . 0E-9
Woollcott K. Smith, J. Frederick Grassle, and David Kravitz

Notes and Discussions - Environmental Survey Design: A Time Series Approach . 0E-9
Woollcott K. Smith

Measures of Diversity with Unbiased Estimators 0E-9
Woollcott K. Smith, J. Frederick Grassle, and David Kravitz

GENERAL

Weight and Stability of DSRV *ALVIN*, 1978 . . . . . 0E-10
Arnold G. Sharp

Stress and Strain in Marine Pressure Vessels 0E-10
James W. Mavor, Jr.

A Water Sampling System for Long Deployment Sediment Monitoring Instrument . . 0E-10
David S. Hosom and Kenneth W. Doherty.

TABLE OF CONTENTS

Page No.

DEPARTMENT OF PHYSICAL OCEANOGRAPHY PO-1

Ocean Circulation

Current System South and East of the Grand Banks of Newfoundland PO-3
R. Allyn Clarke, Harry W. Hill, Robert F. Reiniger and Bruce A. Warren

Thermal Feedback on Wind-Stress as a Contributing Cause of the Gulf Stream . . PO-3
Lloyd Regier, Henry Stommel and David Behringer

The Benjamin Franklin and Timothy Folger Chart of the Gulf Stream, c. 1768 . . PO-3
Philip L. Richardson

Rings, Eddies

Tracking a Kuroshio Cold Ring with a Free-Drifting Surface Buoy PO-3
Robert E. Cheney, Philip L. Richardson and Koichi Nagasaka

The Birth and Death of a Warm Core Ring PO-3
Gabriel T. Csanady

A Census of Gulf Stream Rings, Spring 1975 . . . . . PO-4
Philip L. Richardson, Robert E. Cheney and Valentine Worthington

Observations of Energetic Low Frequency Current Fluctuations in the Charlie-Gibbs Fracture Zone PO-4
William J. Schmitz, Jr. and Nelson G. Hogg

Surface Layer Processes and Meteorology

A Note on the Mean Circulation in the Mid-Atlantic Bight PO-4
Robert C. Beardsley and Clinton D. Winant

Wind Effects on Surface to Bottom Fronts PO-4
Gabriel T. Csanady

Surface Mixing Layers in the Sargasso Sea PO-5
Ann E. Gargett, Thomas B. Sanford and Thomas R. Osborn

Recent Observations in the Equatorial Indian Ocean PO-5
James R. Luyten

Winter Circulation in the Western Gulf of Maine: Part 2: Current and Pressure Observations PO-5
John A. Vermersch, Robert C. Beardsley and Wendell S. Brown

A Comparison of Some Shallow Wind-Driven Currents PO-6
Clinton D. Winant and Robert C. Beardsley

Turbulence and Mixing, Topographic Effects

Effects of Variations in Eddy Diffusivity on Horizontal and Vertical Property Distributions in the Oceans PO-6
Laurence Armi

Poleward Heat Flux and Conversion of Available Potential Energy in Drake Passage . PO-6
Harry L. Bryden

Island Trapped Waves: Theory and Observations from around Bermuda . . . PO-6
Nelson G. Hogg

The Anatomy of the Antarctic Polar Front in the Drake Passage PO-7
Terrence M. Joyce, Walter Zenk and John M. Toole

Geostrophic Turbulence PO-7
Peter B. Rhines

Internal Waves

Internal Wave Variability during the Internal Wave Experiment (IWEX) . . . PO-7
Claude Frankignoul and Terrence M. Joyce

TABLE OF CONTENTS

Page No.

Fine Structure in the Antarctic Polar Front Zone: Its Characteristics and Possible Relationship to Internal Waves P0-8
Daniel T. Georgi

Tidally-Generated Internal Wave Packets in Massachusetts Bay, U.S.A.; Preliminary Physical and Biological Results P0-8
Loren R. Haury, Melbourne G. Briscoe and Marshall H. Orr

Vertical Coherence of the Internal Wave Field from Towed Sensors P0-8
Eli J. Katz and Melbourne G. Briscoe

Observations of Interaction between the Internal Wavefield and Low Frequency Flows in the North Atlantic P0-9
Barry R. Ruddick and Terrence M. Joyce

Theoretical Models

An Experimental and Numerical Study of the Secular Spin-up of a Thermally Stratified Rotating Fluid P0-9
Robert C. Beardsley, Kim D. Saunders, Alex C. Warn-Varnas and John M. Harding

Mean Flow Generation by Topographic Rossby Waves P0-9
Alain Colin de Verdière

An Example of Eddy-Induced Ocean Circulation P0-10
William R. Holland and Peter B. Rhines

On the Mediterranean Outflow in the North Atlantic: Part I, 2-D Advective Diffusive Model with a Mid-Ocean Ridge P0-10
Terrence M. Joyce

Simulated Dynamic Balances for Mid-Ocean Mesoscale Eddies P0-10
W. Brechner Owens

Eddy-Driven Circulation of the Ocean: A Vorticity-Transport Theory P0-11
Peter B. Rhines

A Theoretical Discussion of Eddy-Driven Mean Flows P0-11
Peter B. Rhines and William R. Holland

Others

Calculation of the Potential Temperature of Seawater from the Effect of Pressure on Entropy P0-12
Alvin Bradshaw

Geostrophic Vorticity Balance in Mid-Ocean P0-12
Harry L. Bryden

The Mean Pressure Field of the North Atlantic P0-12
Gabriel T. Csanady

Modal Properties of Antarctic Intermediate Water in the Southeast Pacific and the South Atlantic P0-13
Daniel T. Georgi

A Depth-Controlled Tow System for Hydrographic and Current Measurements with Applications P0-13
Eli Joel Katz and Warren E. Witzell, Jr.

Scales of Motion in the Subtropical Convergence Zone P0-13
Ants Leetmaa and Arthur D. Voorhis

Technical Reports

Bibliography(1) and Inverse Analysis of the Trimoored Internal Wave Experiment (IWEX)(2) P0-14
(1)Melbourne G. Briscoe and Terrence M. Joyce, (2) Jurgen Willebrand, Peter Muller and Dirk J. Olbers

CTD Observations in the Western Mediterranean Sea during Cruise 118, Leg 2 of R/V *CHAIN*, February, 1975 . . . . . P0-14
Harry L. Bryden, Robert C. Millard and David L. Porter

TABLE OF CONTENTS

Page No.

Performance of an Absolute Velocity Profiler based on Acoustic Doppler and Electromagnetic Principles PO-14
John H. Dunlap, Thomas B. Sanford, and Robert G. Drever

Hydrographic Station Data obtained in the Vicinity of Georges Bank, May and August, 1976 . . . . . PO-15
Richard Limeburner, John A. Vermersch and Robert C. Beardsley

Auto and Cross-Bispectral Analysis of Scalar and Vector Time Series: Programs, Program Descriptions, and Tests with Artificial Data PO-15
Gerard H. Martineau and Melbourne G. Briscoe

Bispectra of Internal Waves PO-15
C. Henry McComas III

Ranges and Extremes of the Natural Environment in and about the Hawaiian Archipelago related to Design Criteria for Ocean Thermal Energy Conversion Plants PO-15
Arthur R. Miller

A Digital Tape Format for Woods Hole Oceanographic Institution CTD Data . . . PO-15
Robert C. Millard, Anselm Blumer and Nancy Galbraith

A Compilation of Moored Current Data and Associated Observations (MODE Site, Vol. XVI, 1971-1975) PO-16
Susan Tarbell and Ann Spencer

A Compilation of Moored Current Meter Data and Associated Oceanographic Observations, Vol. XVII (POLYMODE Array II Data) PO-16
Susan Tarbell, Ann Spencer and Richard E. Payne

TABLE OF CONTENTS

Page No.

MARINE POLICY AND OCEAN MANAGEMENT MP-1

Primary Impacts of Growing Aquatic Plants for Energy MP-3
Thomas Hruby

Impacts of Large-Scale Algal Biomass Systems MP-3
Thomas Hruby

Salt Marsh Nitrogen Flow Analysis: Fertilization and the Allocation of Biological Productivity MP-3
Thomas M. Leschine

Input-Output Analysis for Salt Marsh Bioproductivity MP-3
Thomas M. Leschine and Leah J. Smith

What's Happening at the Fish Pier? MP-4
Margaret Linskey

The Growth of Aquaculture in Developing Countries: Potentials, Patterns, and Pitfalls MP-4
Yoshiaki Matsuda

Implications of the Japanese Experience in Aquaculture Development for Thirty-three Food-short Countries MP-4
Yoshiaki Matsuda

Factors Limiting the Development of Aquaculture: Japanese Experience MP-4
Yoshiaki Matsuda

Shrimp that Slept: How Mexico Underdeveloped its Rural Pacific Fisheries . . . MP-5
James R. McGoodwin

Pelagic Shark Fishing: A Context for Cooperative Action MP-5
James R. McGoodwin

Remarks *on* Aquaculture Policies in Latin America MP-5
Francisco J. Palacio

New England Fishing, Processing and Distribution MP-5
Susan B. Peterson and Leah J. Smith

OCS Drilling Mud Discharges: The Development of Environmental Regulations . . . MP-5
Alison Rieser and Judith Spiller

Case Studies in Economic Effects of Limiting Entry to the Fisheries MP-6
Leah J. Smith

Analysis of Methods for the Culture of *Crassostrea virginica* in New England . . MP-6
George C. Matthiessen and Leah J. Smith

The 'Public Face' of the New England Regional Fishery Council: Year I MP-6
M. Estellie Smith

Transgression, Regression and Evolution MP-7
Judith Spiller

TABLE OF CONTENTS

Page No.

GRADUATE STUDENTS GS-1

The Crustal Structure and Subsidence History of Aseismic Ridges and Mid-plate Island Chains GS-3
Robert Sherman Detrick, Jr.

Seasonal Oscillations in a Mid-latitude Ocean with Barriers to Deep Flow . . . GS-3
Eric Firing

Nonlinear Energy and Enstrophy Transfers in a Realistically Stratified Ocean . . GS-4
Lee-Lueng Fu and Glenn R. Flierl

Fluxes, Dynamics, and Chemistry of Particulates in the Ocean GS-4
Wilford D. Gardner

Studies of Deep-Sea Sedimentary Microtopography in the North Atlantic Ocean . . . GS-5
Roger Donald Flood

The Enzymatic Synthesis of the Yellow Pigment, Sepiapterin, in *Drosophila melanogaster* GS-5
Gwen Grabowski Krivi

Attenuation of Low-Order Modes in Lossy Acoustic Waveguides GS-6
H. David Leslie

Investigations into the Seasonal Deep Chlorophyll Maximum in the Western North Atlantic, and its Possible Significance to Regional Food Chain Relationships . . . GS-7
Peter B. Ortner

Lengths of Intermediate and Deep Seismic Zones and Temperatures in the Downgoing Slab of Lithosphere GS-7
Peter Molnar, David Freedman, and John S.F. Shih

The Vertical Flux of Particulate Organic Matter in the Peru Coastal Current as Measured with a Free-drifting Sediment Trap GS-8
Nick Staresinic

Response of a Pendulum Spar to 2-Dimensional Random Waves and a Uniform Current . . GS-9
George Rodenbusch

A Study of the Velocity Structure in a Marine Boundary Layer - Instrumentation and Measurements GS-9
John Steven Tochko

Rate Zonal Density Gradient Ultracentrifugation Analysis of Repair of Radiation Damage to the Folded Chromosome of *Escherichia coli* GS-10
Kevin Michael Ulmer

Heat Flow in the Weddell Sea GS-11
Victor Zlotnicki, Ian O. Norton, John G. Sclater and R. P. VonHerzen

BIOLOGY

DEPARTMENT OF BIOLOGY

George D. Grice, Department Chairman

AQUACULTURE

OUTDOOR ALGAL MASS CULTURES. I. APPLICATIONS.

Joel C. Goldman

Algal mass culturing research has been carried out in many parts of the world for the past 30 years. Whereas early efforts were directed towards single-celled protein production for human consumption, many new applications have evolved including wastewater treatment, water renovation, nutrient recycling, production of chemicals, aquaculture, and bioconversion of solar energy. Photosynthetic yields over 30 gr dry wt m^{-2} day^{-1} have been attained on occasion in many locations for short periods and yields between 15-25 gr dry wt m^{-2} day^{-1} for longer periods are now common. It appears that bioconversion of solar energy with algal cultures is not attractive because of the tremendous quantities of land, water and nutrients required. Similarly, single-celled protein from microalgae is beset with numerous problems associated with nutritional quality, toxicology, and economics. The main attractiveness of algal mass cultures is that they have great versatility to be integrated into multi-use systems for simultaneously solving several environmental problems. Their use probably will be limited to small specific applications and not on the massive scale projected in the past.

Supported by: *U.S. Department of Energy Contract EG-77-S-02-4151.*

OUTDOOR ALGAL MASS CULTURES. II. PHOTOSYNTHETIC YIELD LIMITATIONS

Joel C. Goldman

The photosynthetic conversion of sunlight energy into algal biomass in large-scale outdoor cultures is controlled by the availability of sunlight, the photosynthetic machinery of algae, nutrients, temperature, and the design characteristics of the culture system. For the situation in which light is made the growth rate limiting factor, there is an upper limit in the light conversion efficiency of a large-scale culture, which translates to a maximum potential yield of 30-40 gr dry wt m^2 day under ideal sunlight conditions. In practice, the best yield data for outdoor cultures in various locations in the world has been 30-40 gr dry wt m^{-2} day^{-1} for short periods and considerably less for longer durations. The development of large-scale mass cultures involves many considerations, but the two major design parameters for optimizing yields at a particular time of year are the flow rate through the culture and the depth.

Supported by: *Department of Energy Contract EG-77-S-02-4151.*

SOME ASPECTS OF THE GROWTH AND YIELD OF Gracilaria follifera *IN CULTURE*

Brian E. Lapointe and John H. Ryther

A series of outdoor, continuous-flow seawater cultures (50 liter; 0.23 m^2) were used to investigate the effects of culture density (kg/m^2), nutrient loading (total nitrogen input/day) with both NH_4^+-N and NO_3^--N, and turnover rate (flow rate/culture volume) on the growth and yield of *Gracilaria follifera* v. *angustissima* (Harvey) Taylor (Gigartinales). Although specific growth rates as high as 60% per day were recorded for *Gracilaria* at low densities (0.4 kg wet wt/m^2) in summer conditions, maximum year-round yields were obtained at densities of 2.0-3.0 kg wet wt/m^2. Above a minimal daily nitrogen loading, yield of *Gracilaria* was independent of nutrient concentration, nitrogen loading or whether nitrogen was in the form of NH_4^+-N or NO_3^--N, but was highly dependent upon flow rate. The time weighted mean annual production during 1976-77 was 34.8 g dry wt/m^2/day or 127 metric tons/hectare/year based on 12-months continuous operation at near optimal densities and flow rates in the non-nutrient limited culture system.

Support by: *Department of Energy Contract E(11-1) 2948 and NOAA Office of Sea Grant 04-6-158-44016.*

THE EFFECT OF TEMPERATURE ON GROWTH, PHYSIOLOGY AND GAMETOGENESIS IN THE MANILA CLAM Tapes philippinarum *(ADAMS AND REEVE, 1850).*

Roger L. Mann

Populations of the Manila clam (*Tapes philippinarum* Adams and Reeve, 1850) were maintained at temperatures of 12, 15, 18 and 21°C for a period of 19 weeks. Regular assays were made of ammonia excretion rate following which animals were sacrificed for estimation of dry meat weight, dry shell weight, biochemical composition, and gonadal development. *T. philippinarum* increased from an initial dry meat weight of 291.5 mg to final values of 957.9, 733.0, 735.0 and 586.0 mg at 12, 15, 18 and 21°C respectively.

An initial increase in percentage carbohydrate content was evident at all temperatures. This was followed by carbohydrate depletion associated with gametogenesis, the transition from accumulation to depletion occurring earlier with increasing temperature. Ripe gonadal material was evident at all temperatures, but

spawning was only evident at 15, 18 and 21°C. Ammonia excretion data for 12, 15 and 18°C exhibited an allometric relationship to meat weight, data for 21°C did not.

In Press: *J. Exp.Mar.Biol.Ecol.*

Supported by: *NOAA Sea Grant 04-6-158-44016 and Jessie Smith Noyes Foundation, Inc.*

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

Roger L. 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 "depuration" 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.

Published in: *Proc.World Mariculture Soc. Annual Meeting (Honolulu,HI) 1979.*

Supported by: *Sarah Scaife Foundation.*

OPPORTUNITIES FOR VIRUS TRANSPORT WITHIN AQUATIC AND TERRESTRIAL ENVIRONMENTS

Theodore G. Metcalf, Ronald Comeau, Robert Mooney and John H. Ryther

Virus transmission among animals living within a mariculture system was shown following the introduction of enteric viruses. Transmission events depended upon the development of a passive virus carriage status in animals used as a food source by another animal. A transport process beginning with viruses in sewage effluents resulted in the passage of virus sequentially from shellfish to polychaete worms to flounder or lobsters.

Soil macroinvertebrates became virus carriers following ingestion of food with added virus. Virus accumulation, survival and elimination data for five macroinvertebrate hosts was determined. Study results showed virus transmission events of potential health effect significance to man could occur among animals making up hypothetical food chains following the introduction of enteric virus pathogens into terrestrial or aquatic environments.

In Press: *Proc.Conf. on Assessment of Risks and Health Effects resulting from Application of Municipal Sludge to Land Surfaces (U.Texas Press).*

Supported by: *NSF - RANN, 20/43884.*

BIOMASS PRODUCTION BY SOME MARINE AND FRESHWATER PLANTS

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

Comparative growth studies have been made of the red seaweed *Gracilaria tikvahiae* and the freshwater macrophytes *Eichhornia crassipes* (water hyacinth), *Lemna minor* (duckweed), and *Hydrilla verticillata*. Effects of nutrient concentration, flow rate of water through the culture system (retention time), and plant density on yield have been determined for each species. Relationships between wet weight, dry weight, and ash-free dry weight (organic content) have also been determined for each species collected from the wild and from cultures, the latter determined as a function of nutritional conditions of the plants.

Yields in culture have been compared with those in nature, and yields from different culture techniques involving various costs and inputs of energy have been evaluated.

Mean annual ash-free dry weight yields of *Gracilaria* and water hyacinths grown under the best culture condition throughout the year at Fort Pierce, Florida were 17.4 and 17.3 grams/m^2/day respectively, roughly equivalent to 25 tons/acre/year.

Presented at: *Second Annual Symposium on Biomass for Fuels, Rensselaer Polytechnic Institute.*

Supported by: *Dept. of Energy Contract EY-76-S-02-2948 A01.*

AQUACULTURE: WETLANDS AND ENRICHED WATER SYSTEMS

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

Rapid biomass increases of aquatic weeds are often a consequence of eutrophication of natural waters. Since this enhanced plant growth results from nutrient enrichment, these weeds might be used as a means of tertiary sewage treatment and as a potentially useful biomass source. Growth studies of the aquatic plants water hyacinth *(Eichhornia crassipes)*, common duckweed (*Lemna minor*), giant duckweed (*Spirodela polyrhiza*) and *Hydrilla verticillata* were conducted in an aquaculture system of ponds receiving an enriched nutrient medium. Effects of culture density, harvest frequency and nutrient availability on plant growth were investigated. Comparative growth studies with these species in natural waters indicated that substantially higher yields were attained in the aquaculture system. The most productive plant was *Eichhornia crassipes*, which had a mean productivity of 24.4 g/m^2/day.

Published in: *National Wetlands Symposium - Nov.7-10 Disney World,FL.*

Supported by: *Dept. of Energy Contract EY-76-S-02-2948.*

BENTHOS

ZONATION AND ECOLOGY OF DEEP-SEA BENTHOS

Richard L. Haedrich and Gilbert T. Rowe

The faunas of the deep ocean bottom are zoned with depth. Off southern New England we recognize seven megafaunal regions between 200 and 5000 m and six macrofaunal regions between 32 and 3600 m. The fauna of a region is distinct and fairly homogeneous, and can be characterized in terms of overall abundance, biomass, diversity, and dominant species. Abundance in general declines with depth, with high anomalies at the base of the slope and in submarine canyons. Diversity increases to a maximum at moderate depths and differs from group to group, but is the least at greatest depths. Zones are most clearly defined on the continental slope and are not as marked across the continental rise. Varied autecologies are found in the deep-ocean megafauna, with no one sort predominating. We suggest that the patterns in zonation result from variations in food supply, interactions between species, and the pressure range over which enzyle systems comfortably function. Generalities derived from study of the macrofauna may not apply to all segments of the deep-ocean community.

Presented in: *AAAS Symposium on Deep-Sea Ecology, Jan.4, 1979 (Houston)*

Supported by: *NSF Grant OCE 76-21878.*

THE MEGABENTHIC FAUNA IN THE DEEP SEA SOUTH OF NEW ENGLAND

Richard L. Haedrich, Gilbert T. Rowe and Pamela T. Polloni

The data from 195 benthic trawls made between 40 and 5000 m show that the fauna is zoned with depth, the pattern reflecting the fact that areas of rapid faunal change separate regions of relative faunal homogeneity. Distinct faunal assemblages with characteristic catch rates, diversity, and dominant species are found on the shelf (40-264 m), upper continental slope (283-650 m), middle continental slope (653-1290 m), lower continental slope (1380-1947 m), the transitional region from slope to rise (2115-2481 m), the upper continental rise (3244-3470 m), and lower continental rise to abyssal plain (3879-4968 m). Catch rates and diversity are greatest on the lower continental slope and transition to the upper rise, and are lowest at the greatest depths. Dominance, particularly by echinoderms, is an important aspect of community structure. The three major taxa represented (decapod crustaceans, echinoderms, and fishes) do not always display the same patterns within and between assemblages. Generalities derived from study of a single group need not apply to all segments of the deep ocean community. Overall patterns in the megafauna are like those described in other groups and areas, but species assemblages are not the same everywhere and perhaps too much has been made of the horizontal extent of zones. Trophic level is related to degree of zonation, but where predators are generalists their ranges may be wide rather than restricted.Diversity patterns can be understood in terms of the interrelationships of predation, competition, environmental heterogeneity, and trophic level. Faunal zones are of importance as the geographical units within which evolution, community development, and diversification take place.

Supported by: *NSF Grant OCE 76-21878; ONR Contract N00014-74-C-0262;NR-083-004.*

DEVELOPMENTAL ABERRATIONS ASSOCIATED WITH TWINNING IN LABORATORY REARED SEA URCHIN.

Nancy H. Marcus

Twinned sea urchins of *Arbacia punctulata* were reared from single first cleavage blastomeres through metamorphosis to reproductive adult, in the laboratory. A pair of metamorphosed urchins, reared in the same

container, with adequate food, typically differed in size, and gross morphology. Aberrant plate variations of the normal apical system arrangement for the species were expressed by a significantly greater number of twinned urchins than controls derived from whole zygotes. The influence of early embryogenesis on the development of adult features is discussed.

Supported by: *W.H.O.I. Postdoctoral Fellowship.*

THE SIZE-DEPTH RELATIONSHIP IN DEEP OCEAN ANIMALS

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

In response to Thiel's (1975) hypothesis that the food-limited deep sea is a small organism habitat, further data on average size of individuals representing various deep sea taxa are presented. Our data were gathered with trawls and box corers between 200 and 5000 meters in the western North Atlantic. For echinoderms, decapods and macrofauna there appears to be no steady, logarithmic decline in size with increasing depth, but fishes are bigger - deeper.

Supported by: *NSF Grants GA-31235X; DES 74-22339 and OCE 76-21878.*

SPERMATOPHORES OF SIX EAST NORTH AMERICAN PYRAMIDELLID GASTROPODS AND THEIR SYSTEMATIC SIGNIFICANCE

Robert Robertson

The systematics of the Pyramidellidae, one of the largest families of gastropods, has so far been based on shell characters exclusively. These ectoparasites lack radulae, so even radular characters are missing. This paper gives the first results of a study determining the relevance of biological characters in the systematics of the east North American odostomioid pyramidellids. Sexual biology seemed the right first approach.

Supported by: *NSF Grant DEB 76-18835.*

THE BIOTA AND BIOLOGICAL PROCESSES OF THE CONTINENTAL SLOPE

Gilbert T. Rowe and Richard L. Haedrich

Life on continental slopes is characteristically zoned with depth. Faunal variation across the slope appears to occur more rapidly than anywhere else in the deep-ocean environment, but the causes of the narrow zonation are not known. A diversity of causes is possible, including competition for a diminishing resource (food), very efficient predation, pressure effects on enzymes, and also conditions such as extremely low dissolved oxygen or variations in the physical properties of the sediments. The composition of the fauna on continental slopes is not entirely unique, sharing species both with the continental shelf and continental rise, but nonetheless the slope can be considered a distinct biological province. The abundance of life and rates of physiological processes are intermediate between those of the shallow continental shelf and the abyss. Rates of change do not follow smooth gradients across the slope. At the base of the slope, where organic-rich sediment from shallow depths have accumulated, there is an important transition zone to the more truly oceanic conditions of the continental rise. Petroleum and phosphorite resources on the continental slope, using biological criteria, would most likely occur in regions historically characterized by upwelling, high productivity and low oxygen concentrations. Like the fauna itself, these resources should occur in zones. Because continental slope depths and beyond are important in the remineralization of organic matter, those involved in the exploration for and utilization of deep-sea resources must keep in mind that alteration of normal biological processes there might adversely affect the natural and vital biochemical cycling.

Published in: *Chapter in a book, Doyle and Pilkey, editors.*

Supported by: *NSF Grant OCE 76-21878.*

MATING SYSTEMS IN PORCELLIONID ISOPODS: MULTIPLE PATERNITY AND SPERM MIXING IN Porcellio scaber *Latr.*

Clay Sassaman

The enzyme phosphoglucose isomerase is encoded by a multi-allelic gene locus in North American populations of the wood louse *Porcellio scaber.* Laboratory crosses using virgin females have documented the Mendelian nature of PGI inheritance for seven electrophoretically distinct alleles. Several additional rare alleles occur in natural samples. This multiallelic polymorphism has been employed to determine the frequency of multiple paternity of broods in a natural population by examining the mother-offspring (family) genotype combinations of 20 field-collected pregnant females. The data indicate that the great majority of broods (83-95%) are multi-paternal and that each of several males usually makes a substantial spermic contribution to any particular one.

Supported by: *W.H.O.I. Postdoctoral Fellowship.*

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

A RADIO TAG FOR BIG WHALES

William A. Watkins

A means of recognizing individual whales at sea is needed for an understanding of their behavior and population movements. To try to meet this need a remotely implanted radio whale tag has been developed and tested on whale carcasses, as well as on free-swimming whales. This tag is an outgrowth of our radio whale tagging experiments that began in 1961. A new point has been devised for penetration of whale blubber. The next step planned for the summer of 1978, is a test series to find out if a whale will really wear the tag.

Published in: *OCEANIS, Spring 1978.*

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

RADIO TAGGING REPORT OF FINBACK AND HUMPBACK WHALES

William A. Watkins, James H. Johnson and Douglas Wartzok

Two finbacks (*Balaenoptera physalus*) and three humpback whales (*Megaptera novaeangliae*) were tagged and tracked in Prince William Sound, Alaska (1 - 30 June, 1978) with 27 and 30-MHz radio tags. The implantation of the tag was found to be essentially identical for the two species. The whales returned to apparently normal routines within a short time of tagging. The 1978 radio whale tags remained in place for only two to three weeks, generally protruding more and more with time. There was no evidence of infection. The radio signal provided positive identification of the tagged whales and permitted tracks of the whales' movement as well as detailed studies of their behavior.

Published in: *Special publications NMFS-NW Fisheries Center, Oct.1978.*

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

DISTINCTIVE BREEDING SEASON CALLS OF THE HARP SEAL, Phoca groenlandica.

William A. Watkins and William E. Schevill

Underwater calls of *Phoca groenlandica*, the harp seal, recorded during the early March breeding season (1967, Gulf of St.Lawrence) were often found to have increasing amplitude and increasing frequency (Hz) components opposite to those that generally characterize ambient noise. This "reversed" characteristic together with abrupt endings and repetitive patterns of these sounds create distinctive breeding season calls that could be used to recognize the reproductive herd at a distance. Such acoustic distinctions depend on the habituation of the seal (or human) listener to underwater sound, but minimizes the effects of masking of the breeding season calls by background noise.

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

A RADIO WHALE TAG

William A. Watkins, Douglas Wartzok, Hugh B. Martin, III, and Romaine R. Maiefski

A radio whale tag was developed for tracking large whales at sea, using both shipboard and aerial tracking systems. A series of tests have shown that the tags were retained by both finback and humpback whales for periods of two to three weeks and provided good new information on the behavior of these whales. The radio tag had a 200 m watt, 27 to 30-MHz transmitter housed in a tubular (1.9 x 24 cm) stainless steel pressure case with a 45 cm whip antenna. The whale tag was launched from a modified 12-gauge shotgun and implanted into the blubber of large whales at distances to 30 meters. The tag was implanted leaving only the antenna protruding. A seawater switch turned the transmitter off underwater to give a potential life of up to 12 months from the power supply of three organic lithium batteries. Tagged whales could be tracked by ship within 5 to 25 km depending on antenna orientation and exposure. A radio tag for whales has long been needed to permit assessment of behavior, group movement, population distribution, etc. Telemetry and satellite tracking could extend the usefulness of a longer term radio whale tag.

Supported by: *ONR Contracts N00014-74-C-0262;NR 083-004 and N00014-75-C-0701;NAS 2-9300.*

A POINT FOR PENETRATING WHALE BLUBBER

William A. Watkins

A point for penetrating blubber was designed for use on a radio whale tag. Five different shapes were compared and tested on fresh finback carcasses brought in to the whaling station in Iceland. One point shape consistently performed better than the others, penetrating blubber in a straight line with the trajectory of the tag projectile, even at low impact angles. The radio tag with this point penetrated better than the *DISCOVERY* whale mark. The point for blubber had cutting edges for efficient penetration and relief channels to avoid the build-up of high pressure in front of the point.

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

ACOUSTICS AND THE BEHAVIOR OF SPERM WHALES

William A. Watkins

The sounds heard from sperm whales underwater are discussed, the literature on the acoustics of these whales is reviewed, and their behavior relative to sound is analyzed. It is concluded that both echo information and communication are probably a part of the acoustic behavior of sperm whales. Our observations seem to relate the sounds more clearly to social interaction, but we may also be dealing with a different biosonar system.

Published by: *Proceedings, NATO Advanced Study Inst. on Animal Sonar Systems, Plenum Press, N.Y. July, 1979*

Supported by: *ONR Contract N00014-84-C-0262;NR 083-004.*

FISHES

PARASITISM AND ECOLOGICAL RELATIONSHIPS AMONG DEEP-SEA BENTHIC FISHES

Ronald A. Campbell, Richard L. Haedrich and Thomas A. Munroe

We have studied the metazoan parasite fauna of 52 species of deep-living benthic fishes from depths of 53 to 5000 m off the New York Bight (30-40°N, 70-72°W). 17144 parasites were recovered from 1712 fish. Infection rate was 80%, with an average of 12.5 worms/host. Percentage occurrence by group among all fishes was Monogenea 12.9%, Digenea 48%, Cestoda 22.1%, Nematoda 54.4%, Acanthocephala 3.8%, and Copepods 4.5%. Differing composition of the parasite fauna in different fish species reflected differences in diet. Specialized feeders are rather distinct; generalized feeders, which predominate, show overlaps in parasite fauna. In individual species, changes in diet with growth can be seen in changes in the parasite fauna. Infection rate is directly related to abundance of the free-living fauna; hence fish from within submarine canyons are more heavily infested than those living without. Biogeographically, the deep-ocean parasite fauna is very similar to that of other cold-water regions of the world. Although it contains fewer families than shallow faunas, the deep-sea parasite fauna is not unusual in terms of abundance, diversity, or host specificity. At the greatest depths parasite abundance and diversity dramatically decline.

Supported by: *NSF Grants DEB 76-00103 and OCE 76-21878.*

BAITED CAMERA LOWERINGS IN THE GALAPAGOS RIFT

Daniel M. Cohen, Richard L. Haedrich, and Pamela T. Polloni

Nine lowerings of a free-vehicle baited camera in the Galapagos hot vents area produced 3300 analyzable photographs. These show a relatively high diversity of fishes, particularly macrourids, zoarcids, and ophidiids, but relatively few invertebrates other than galatheid and brachyuran crabs. Behavior in general was lethargic. The faunal mix from lowering to lowering was not always the same suggesting quite local ranges. The abundance of fish around the bait was about an order of magnitide less than in northwestern Atlantic lowerings at comparable depths (2800 m). Hence the enhanced production around the hot vents does not manifest itself at higher trophic levels. The influence of the vents must be considered biologically very local.

Supported by: *NOAA and NSF Grant OCE 76-21878.*

DEEP-SEA FISH

Richard L. Haedrich

The systematic composition, general morphology, distribution and ecology of deep-sea fish faunas, both pelagic and benthic, are treated in this short article. Contrasts between pelagic and benthic groups reflect their probably different evolutionary histories.

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

DISTRIBUTION OF BOTTOM FISHES IN THE DENMARK STRAIT AND IRMINGER SEA

Richard L. Haedrich and Gerhard Krefft

Analyses of 27 bottom trawl collections from the Denmark Strait and Irminger Sea show that five faunal assemblages of fishes can be identified. These are separable on the basis of faunal composition, diversity, evenness, catch rate, and the combination of depth and temperature at which each occurred. One group is found at 2026-2058 m depth and temperatures of 1.3-3.4°C, a second at 763-1503 m and 3.9-5.6°C, a third at 280-776 m and 1.4-7.4°C, a fourth at 493-1519 m and 0.1-3.0°C, and a fifth at 330-693 m and (-)0.7-(+)0.5°C. The assemblages are like those described for fishes trawled on the Iceland-Faeroe Ridge during an earlier expedition in 1960, although the relative dominance by commercial species has declined. Cold-water assemblages and species are found along the path of the

Norwegian Sea water that flows south on the bottom through the Denmark Strait and down across the continental slope to the west. The percentage of primary deep-water species in each assemblage increases evenly with depth, suggesting a gradual and continuing invasion of the deep sea in this region by phylogenetically younger secondary deep-water forms. The smooth transition from an essentially shallow-water fauna to an essentially deep-water one as seen in the demersal fishes contrasts with the more abrupt transition found in pelagic fishes. The meso- and bathypelagic forms, presumably higher specialized and finely tuned to their environment, are more successful in resisting invasion and colonization from newer groups. In the demersal assemblages, there is a good correlation between the number of species present and the heterogeneity of the local environment as reflected in the temperature range over which each of the assemblages occurs.

In Press: *Deep-Sea Research 25: 705-720 (1978).*

Supported by: *NSF Grants 31235X, 31365X and OCE 76-21878.*

EXPERIMENTAL EVIDENCE OF GEOMAGNETIC ORIENTATION IN ELASMOBRANCH FISHES

Adrianus J. Kalmijn

Marine sharks, skates, and rays are endowed with an electric sense that enables them to detect voltage gradients as low as 0.01 μV/cm within the frequency range of direct current (DC) up to about 8 Hz. Their electroreceptor system comprises the ampullae of Lorenzini, which are delicate sensory structures in the snouts of these elasmobranch fishes. Sharks, skates, and rays use their electric sense in predation, sharply cueing in on the DC and low-frequency bioelectric fields of their prey. Swimming through the earth's magnetic field, they also induce electric fields that may provide them with the physical basis of an electromagnetic compass sense. Their ability to orient magnetically has in fact been demonstrated in recent training experiments.

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

ELECTRIC AND MAGNETIC SENSORY WORLD OF SHARKS, SKATES, AND RAYS.

Adrianus J. Kalmijn

Review and recent successes on electric and magnetic orientation in elasmobranch fishes.

Published in: *Sensory Biology of Sharks, Skates, and Rays. E.S.Hodgson and R.F.Mathewson. Eds. U.S.Gov't.Prin. Off.,Washington,D.C. 1978.*

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

THE SHARK'S SIXTH SENSE

Adrianus J. Kalmijn and Kenneth J. Rose

Field work on the shark's dependence on its electric sense in predation.

Published in: *Natural History Magazine 87(3): 76-81. (1978).*

Supported by: *Eppley Foundation of Research.*

MICROBIOLOGY

DEOXYRIBONUCLEIC ACID BASE COMPOSITION OF CYANOBACTERIA

Michael Herdman, Monique Janvier, John B. Waterbury, Rosemarie Rippka, Roger Y. Stanier and Manley Mandel

The deoxyribonucleic acid base compositions of 175 strains of cyanobacteria have been determined by thermal denaturation or by CsCl density gradient centrifugation. A summary of all data now available for this prokaryote group is presented and the taxonomic and evolutionary implications are discussed.

In Press: *Journal of General Microbiology.*

Supported by: *NSF Grant OCE 75-21270.*

WORKSHOP ON MICROBIAL DEGRADATION OF POLLUTANTS IN MARINE ENVIRONMENTS

THE ULTIMATE SINK

Holger W. Jannasch

The discussion of the marine environment as a site for degradation processes is introduced by reviewing some fundamental concepts of microbial ecology. The effective environment for bacterial and fungal activities is the micro-habitat of the individual cell. Characteristics of the aquatic environment are closely related to the physical and chemical properties of water in general, and of seawater in particular. On the macro-scale, the marine environment is divided, more for logistic than for microbiological reasons, into estuaries, littoral zones, water column, sediment, etc. For open ocean waters, the extreme dilution of metabolizable organic materials and pollutants are characteristic and pose specific problems of microbial uptake and degradation. As an example, a microbial degradation study in the deep sea is discussed with emphasis on hydrostatic pressure and

low temperatures as envitonmental factors. Microbial activities were found to be reduced at deep sea conditions, and barophilic responses of natural microbial populations were not found. The consequences for offshore and deep sea dumping of organic waste materials are discussed.

Published as: *Key Note Address.*

Supported by: *NSF Grant OCE 77-19766 and ONR Contract N00014-74-C-0262;NR 083-004.*

MICROBIAL ECOLOGY OF AQUATIC LOW-NUTRIENT HABITATS

Holger W. Jannasch

Microorganisms inhabiting low-nutrient waters have been found to exhibit relatively high affinities (low saturation constants) for growth on a number of tested substrates likely to be limiting under natural conditions. In studies on population dynamics solely based on kinetic growth parameters, the actual results of competition were predictable from constants measured in pure culture. Growth rates of bacterial isolates can be determined in unsupplemented low-nutrient seawater where the type of growth limitation is not known. Experiments showed that certain environmental conditions may result in threshold concentrations of limiting nutrients below which no further utilization occurs. Suspended particulate materials, as sources of solid or adsorbed dissolved organic substrates, are more effective for microbial growth in low- than in high-nutrient habitats.

Published in: *Strategy of Microbial Life in Extreme Environments. M.Shilo ed., Dahlem Konferenzen,Berlin.*

Supported by: *NSF Grant OCE 77-19766.*

MICROORGANISMS AND THEIR AQUATIC ENVITONMENT

Holger W. Jannasch

This introductory chapter summarizes and discusses the specific characteristics of the aquatic environment with respect to growth survival, and specific metabolic activities of microorganisms.

Published in: *Environmental Biogeochemistry and Geomicrobiology, Chap.2.*

Supported by: *NSF Grant OCE 77-19766.*

MICROBIAL TURNOVER OF [illegible] 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 pollutants in the deep sea which comprises over 60 percent of the biosphere.

Published in: *Bioscience.*

Supported by: *ONR Contract N00014-74-C-0262;NR 083-004 and NSF Grant OCE-77-19766.*

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_2 and cell material in deep sea sediments using Na-^{14}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.

To be Published in: *"Actes des Colloques du C.N.R.S."*

Supported by: *ONR Contract N00014-74-C-0262;NR 083-004 and NSF Grant OCE 77-19766.*

THE MAGNETIC BEHAVIOR OF MUD BACTERIA

Adrianus J. Kalmijn and Richard P. Blakemore

When separated from the substrate, Blakemore's mud bacteria swim back to the bottom of the sea following the earth's magnetic field lines. Their magnetotactic response appears to be due to the presence of internal ferromagnetic dipole moments of single-domain properties.

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

INACTIVATION OF ENDOTOXIN BY Limulus *AMOEBOCYTE LYSATE*

Ronald Nachum, Stuart E. Stegel, James D. Sullivan, Jr. and Stanley W. Watson

The inactivation of bacterial endotoxin by *Limulus* amoebocyte lysate (LAL) is described. Inactivation of endotoxin with heated extracts of LAL was suggestive of enzymatic mediation as indicated by dependence on time, temperature, pH, and the kinetics of inactivation. Divalent cations were found to inhibit the inactivation of endotoxin by heated extracts of LAL.

Published in: *Journal of Invertegrate Pathology* 32: 51-58, *1978*,

Supported by: *The John A. Hartford Foundation, Inc. 25/77113.*

GENETIC ASSIGNMENTS, STRAIN HISTORIES AND PROPERTIES OF PURE CULTURES OF CYANOBACTERIA

Rosemarie R. Rippka, Josette J. Deruelles, John B. Waterbury, Michael Herdman and Roger Y. Stanier

On the basis of a comparative study of 178 pure strains of cyanobacteria, reasonably representative of this major group of prokaryotes, revised definitions of many genera are proposed. Revisions are designed to permit the generic identification of cultures, often difficult through use of the field-based system of phycological classification. The different characters proposed are both constant and readily determinable in cultured material. The 22 genera recognized are placed in five sections, each distinguished by a particular pattern of structure and development. Generic descriptions are accompanied by strain histories, brief accounts of strain properties, and illustrations; one or more reference strains are proposed for each genus. The collection on which this analysis was based has been deposited in the American Type Culture Collection, where strains will be listed under the generic designations proposed here.

In Press: *Journal of General Microbiology.*

Supported by: *NSF Grant OCE 75-21270,*

THE EFFECT OF PRESSURE UPON THE SOLUBILITY OF OXYGEN IN WATER. IMPLICATIONS OF THE DEVIATION FROM THE IDEAL GAS LAW UPON MEASUREMENTS OF FLUORESCENCE QUENCHING

Craig D. Taylor

The effect of pressure upon the solubility of oxygen in water compressed up to 500 atmospheres (atm) was directly measured. Pressurized aqueous solutions were allowed to equilibrate with a low pressure atmosphere (air, total pressure 1 atm; oxygen-partial pressure, 0.2 atm) across a gas-permeable, pressure-resistant teflon membrane, and the equilibrium molar concentration of oxygen determined chemically. The solubility of oxygen in water decreased exponentially with pressure up to approximately 200 atm. At higher pressures decreases in the molar volume of oxygen in solution resulted in a slight deviation from this initial trend. Implications of these results upon measurements of fluorescence quenching by oxygen under conditions of elevated pressure, a probe for studying the structure of Macromolecules, are discussed.

Published in: *Archives of Biochemistry Biophysics* 191:375-384, *1978*,

Supported by: *NSF Grants DES 75-15017 and OCE 77- 19766.*

SOLUBILITY OF OXYGEN IN A SEAWATER MEDIUM WHICH IS IN EQUILIBRIUM WITH A HIGH PRESSURE OXY-HELIUM ATMOSPHERE

Craig D. Taylor

The molar concentration of oxygen within a seawater medium which was in equilibrium with a high pressure oxy-helium atmosphere was directly measured in pressurized subsamples using a modified version of the Winkler oxygen analysis. When the partial pressure of oxygen within the chamber was one atmosphere or less its concentration in the aqueous phase was adequately described by Henry's Law at total pressures up to 600 atmospheres. This phenomenon, which permits a straightforward determination of dissolved oxygen within hyperbaric systems, resulted from pressure induced compensatory alterations in Henry's Law variables rather than a true obeyance of the Ideal Gas Law. If the partial pressure of a gas contributes significantly to the hydrostatic pressure, Henry's Law is no longer adequate for determining its solubility within the compressed medium.

In Press: *Biomedical Undersea Research.*

Supported by: *NSF Grants DES 75-15017 and OCE 77-19766.*

GROWTH OF A BACTERIUM UNDER A HIGH PRESSURE OXY-HELIUM ATMOSPHERE

Craig D. Taylor

Growth of a barotolerant marine organism, EP-4, in a glutamate medium equilibrated with an oxy-helium atmosphere at 500 atmospheres (atm) total pressure (20°C) was compared to control cultures incubated at one and 500 atm hydrostatic pressure. Relative to the one atm control culture, incubation of EP-4 at

at 500 atm in the absence of an atmosphere resulted in an approximately five-fold reduction in the growth rate, and a significant but time variant reduction in the rate constants for the incorporation of substrate into cell material and respiration. Distinct from the pressurized control and separate from potential effects of dissolution of helium upon decompression of subsamples, exposure of the organism to high pressure oxyhelium resulted either in a loss of viability of a large graction of the cells or the arrest of growth for one-third of the experimental period. After these initial effects, however, the culture grew exponentially at a rate which was three times greater than the 500 atm control culture. The rate constant for the incorporation of substrate into cell material was also enhanced twofold in the presence of high pressure oxyhelium. Dissolved oxygen was well controlled in all of the cultures minimizing any potential toxic effects of this gas.

Published in: *Applied and Environmental Microbiology* 37:42-49, 1979.

MICROBIAL DARK ASSIMILATION OF CO_2 IN THE CARIACO TRENCH

Joh H. Tuttle and Holger W. Jannasch

Dark assimilation of carbon of carbon dioxide has been measured in water sampled from the oxygen-sulfide interface and the deep anoxic zone in the Cariaco Trench. Comparison of rates of interface associated dark assimilation with primary production and organic carbon flux to the deep anoxic water indicates that chemoautotrophic sulfur bacteria cannot be wholly responsible for carbon dioxide assimilation at the observed magnitude. It is suggested that dark assimilation of carbon dioxide near the interface chiefly represents the metabolic activities of facultatively and obligately anaerobic bacteria which use inorganic sulfur compounds as electron acceptors, and sulfide or thiosulfate-oxidizing bacteria whose growth is dependent upon organic carbon.

Supported by: *NSF Grant DES 75-15017.*

QUANTITATIVE METHOD FOR DETERMINING LESS THAN A PG/MI OF LPS

Frederica W. Valois

A spectrophotometric assay was designed for the quantitation of lipopolysaccharide (LPS) in seawater using *Limulus* amebocyte lysate. The sensitivity of the test was increased allowing the detection of less than 0.1 pgLPS/ml.

Supported by: *The John A. Hartford Foundation, Inc.*

WIDESPREAD OCCURRENCE OF A UNICELLULAR, MARINE, PLANKTONIC CYANOBACTERIUM

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

A unicellular cyanobacterium has been observed in and cultured from open ocean waters. It has a widespread distribution and may achieve cell densities as high as 3×10^5 cells/ml within the euphotic zone. The organism is a small coccoid, non-gas vacuolated form assignable to the genus *Synechococcus*. It appears red in culture due to the presence of large amounts of phycoerythrin and is intrinsically marine due to high salt requirements for growth.

Published in: *NATURE (1978).*

Supported by: *NSF Grants DES 75-21270 (to S.W.Watson) and OCE 77-10876 (to R.R.L.Guillard).*

PATTERNS OF GROWTH AND DEVELOPMENT IN PLEUROCAPSALEAN CYANOBACTERIA.

John B. Waterbury and Roger Y. Stanier

The isolation, growth and developmental patterns of 32 strains of pleurocapsalean cyanobacteria representing six genera (*Dermacarpa, Xenococcus, Dermocarpella, Mykosavcina, Chrococcidiopsis and the Pleurocapsa group) are discussed.*

Published in: *Microbiological Reviews, 42:2-44, 1978,*

Supported by: *NSF Grant DES 75-21270.*

DEVELOPMENTAL PATTERNS OF PLEUROCAPSALEAN CYANOBACTERIA (IN DEVELOPMENT AND MORPHOGENESIS IN PROKARYOTES, J.H.PARISH, ED.).

John B. Waterbury

The development patterns of six groups of pleurocapsalean cyansbacteria (*Dermocarpa, Xenococcus, Dermocarpella, Myxosarcina, Chrococcidiopsis* and the pleurocapsa group) were determined by semicontinuous observations of cultures by both light and electron microscopy.

In Press: *Blackwell Scientific.*

Supported by: *NSF Grant DES 75-21270.*

PHYSIOLOGICAL AND MORPHOLOGICAL OBSERVATIONS ON THIOVULUM SP.

Carl O. Wirsen and Holger W. Jannasch

Cell suspensions of *Thiovulum* sp., collected from enrichment cultures, were grown, maintained and harvested for periods up to seven months. In open-flow cultures run with aerated seawater, a continuous supply of hy-

drogen sulfide was provided by diffusion through a semipermeable membrane from either a live culture of *Desulfovibrio estuarii*, neutralized sodium sulfide or a N_2/H_2S gas mixture. Attempts to grow *Thiovulum* in pure culture at varied concentrations of dissolved oxygen and hydrogen sulfide failed in stratified as well as in completely mixed systems. Uptake measurements of ^{14}C-labeled CO_2 and some organic compounds were done with purified cell suspensions and corrected for the activity of heterotrophic as well as autotrophic contaminants as determined in control experiments. Cell populations exhibited maximum uptake activities during formation of the characteristic veils. Substantial uptake of CO_2 in air-saturated seawater showed an optimal concentration of hydrogen sulfide about 1 mM. Glutamate and a selection of vitamins (B_{12}, biotin and thiamine) did not significantly affect the uptake of CO_2. No essential uptake of carbon from acetate, glutamate, mannitol and casamine acids was found. Within the range of error indicated, the data demonstrate the chemolithotrophic nature of *Thiovulum*.

Published in: *Journal of Bacteriology, 136(2): 765-774, Nov. 1978,*

Supported by: *NSF Grants DES 75-15017 and OCE 177, Nov.1978.*

PHYSIOLOGY

EFFECTS OF LOW LEVELS OF HYDROCARBONS ON EMBRYONIC, LARVAL AND ADULT WINTER FLOUNDER, (Pseudopleuronectes americanus)

Walter W. Kuhnhold, Diane Everich, John J. Stegman, James Lake and Richard E. Wolke

Direct exposure of winter flounder eggs to 100 ppb water-accommodated No.2 fuel oil resulted in reduced viable hatch when the exposure duration included both fertilization and embryonic development. Hatching was delayed when exposure included contamination of gametes during gonad maturation, and spinal abnormalities appeared in these fish also. Progeny resulting from gametes contaminated solely during gonad maturation by exposure of adults to 10 or 100 ppb oil showed reduced larval survival and growth. Other developmental events from fertilization through hatching were not influenced by this exposure and progressed normally. The adult females exposed during gonad development possessed fuel oil hydrocarbons in their tissure, yet did not show any exposure-related changes in hepatic cytochrome P-450, benzo(a)pyrene hydroxylase or aminopyrine demethylase. Similarly, hepatic lipogenesis and TCA cycle activity were not affected by this exposure, nor was hepatic histology. Thus, latent affects on reproductive success can occur even though earlier developmental stages or adults appear unaffected.

Supported by: *NOAA Sea Grant 04-6-158-44016.*

FACTORS INVOLVED IN HERBIVORE FOOD PREFERENCE

Mary E. Nicotri

Herbivore food preferences can be measured either in terms of attractiveness or of edibility; these quantities are not necessarily correlated. The isopod *Idotea baltica* is attracted to large, tough, branched algae (perennials) while the amphipod *Ampithoe valida* is attracted to softer, filamentous or bladed ephemerals. Attractiveness for *Ampithoe* is related to the nutrative value of the algae; this is not so for *Idotea* which responds more to algal morphology and availability. *Idotea's* mobility, possible susceptibility to fish predation, and preference for moderate wave exposures may select for a primary response to algae as habitat rather than as food source.

Supported by: *Jessie Smith Noyes Foundation; NOAA Sea Grant 04-6-158-44016; U.S.Dept.of Energy EY-76-S-02-2948 A01.*

HIGH BENZO(A)PYRENE HYDROXYLASE ACTIVITY IN THE MARINE TELEOST FISH Stenotomus versicolor.

John J. Stegeman and Robert Binder

Hepatic microsomal benzo(a)pyrene hydroxylase in the marine fish scup *(Stenotomus versicolor)* was about 10-fold greater than this activity in mice. Levels of aminopyrine demethylase, together with cytochrome and cytochrome reductase components of hepatic microsomal electron transport systems were much lower in scup. The high benzo(a)pyrene hydroxylase in scup was strongly inhibited by 10^{-4} M, 7,8-benzoflavone. The extent of this inhibition did not differ between fish freshly collected and those held for months in aquaria. The data suggest that some marine fish may normally have cytochrome(s) P-450 catalytically resembling cytochrome(s) P-448 in mammals.

In Press: *Biochemical Pharmacology.*

Supported by: *NSF Grants OCE 76-84415 (IDOE), OCE 77-24517; and NOAA Sea Grant 04-6-158-44106.*

HEPATIC AND EXTRAHEPATIC MICROSOMAL ELECTRON TRANSPORT COMPONENTS AND MIXED-FUNCTION OXYGENASES IN THE MARINE FISH Stenotomus versicolor.

John J. Stegeman, Robert L. Binder and Ann M. Orren

NADPH-cytochrome c reductase, benzo(a)pyrene hydroxylase and aminopyrine demethylase activities in hepatic microsomes from the marine fish scup (*Stenotomus versicolor*) were characterized according to dependence on pH, temperature, ionic strength and, in the case of the MFO, Mg^{++}. The kinetic properties of benzo(a)pyrene hydroxylase were variable, depending on protein and substrate concentration, with measured K_ms for benzo(a)pyrene between 4×10^{-7} M and 4×10^{-5} M. K_m for aminopyrine was 7×10^{-4} M and NADPH-cytochrome c reductase had K_ms of 2.1×10^{-5} M and 1.3×10^{-5} M for cytochrome c and NADPH, respectively. NADH supported benzo(a)pyrene hydroxylation at 10% of the rate seen with NADPH and no synergism was observed. Amino-Pyrine demethylation proceeded equally well with either cofactor, and there was synergism when combined.

NADPH- and NADH-cytochrome c reductases were detected in "microsomes" from 14 extrahepatic tissues, including kidney, testis, foregut, gill, heart, red muscle, hindgut, buccal epidermis, pyloric caecae, spleen, brain, lens, ovary ane white muscle. Benzo-(a)pyrene hydroxylase was detected in all but white muscle, while cytochrome P-450 and aminopyrine demethylase were detectable in fewer tissues. Reduced, CO-ligated adsorption maxima in the Soret region were 450 nm for all those but liver, occasionally 449 nm, and heart, 446-447 nm. Estimated turnover numbers for benzo(a)pyrene hydroxylase and aminopyrine demethylase and the influence of 7,8-benzoflavone *in vitro* on benzo(a)pyrene hydroxylase indicate that the cytochromes P-450 in different fish tissues are not catalytically equivalent.

Supported by: *NSF Grants OCE 76-84415, and OCE 77-24517; NOAA Sea Grant 04-6-158-44016.*

BIOACTIVATION OF POLYNUCLEAR AROMATIC HYDROCARBONS TO CYTOTOXIC AND MUTAGENIC PRODUCTS BY MARINE FISH.

John J. Stegeman, Thomas R. Skopek and William G. Thilly

Levels of hepatic cytochrome P-450 and mixed-function oxygenase activity differed markedly between marine fish species *Stenotomus versicolor* (scup) and *Pseudopleuronectes americanus* (winter flounder) and between male and female winter flounder. Hepatic preparations from all these fishes were, however, capable of efficiently activating carcinogenic polynuclear aromatic hydrocarbons to mutagenic derivatives. The results suggest that coastal marine fishes may be at risk to carcinogenic aromatic hydrocarbons in marine sediments.

Supported by: *NSF Grant OCE 77-24517 (IDOE); NOAA Sea Grant 04-6-158-44106.*

In vitro *METABOLISM OF POLYNUCLEAR AROMATIC HYDROCARTONS IN DEEP-SEA FISHES*

John J. Stegeman

Four species of rattails *(Coryphaenoides carapinus, C. armatus, C. leptolepis* and *Nezumia* sp.) from between 1300-3000 m had lower levels of benzo(a)pyrene hydroxylase than do animals living closer to shore. This activity was strongly inhibited by 7,8-benzoflavone, possibly indicating these fish were affected by compounds similar to 3-methylcholanthrene, known to induce a cytochrome P-450 (cytochrome P-448) sensitive to 7,8-benzoflavone in mammals. The presence of environmental hydrocarbons and the ability of deep-sea fishes to metabolize these compounds suggests that bioactivation of chemical carcinogens is possible in the deep sea.

In Press in: *Kaiser (ed.), Comparative Pathology of Abnormal Growth. Raven Press.*

Supported by: *NSF Grant OCE 76-84415.*

PHYTOPLANKTON

THE ROLE OF CHELATORS AND TRACE METALS IN TOXIC DINOFLAGELLATE BLOOMS

Donald M. Anderson and Michael Corbett

The hypothesized link between toxic dinoflagellate blooms (red tide) and the high concentrations of organic material in estuarine and near-shore coastal waters can be the result of both nutritional and toxic characteristics of the trace metal environment. Whis workshop examines the possible chemical and biological processes that might be involved and discusses the analytical problems associated with the collection of meaningful data in the field. The alternative approach of laboratory studies in chemically well-defined seawater media is also discussed in terms of the most important considerations: choice of chelators; background seawater medium; pH control; adoption effects; displacement reactions; glassware; and general procedual methodoligies.

In Press: *Toxic Dinoflagellate Blooms. Proc. 2nd Int'l. Conf. D. Taylor (ed.)*

Supported by: *M.I.T. Sea Grant 04-7-158-44079; International Copper Research Assoc,(Proj. #252); WHOI Ocean Industry Program.*

TOXIC DINOFLAGELLATE BLOOMS IN THE CAPE COD REGION OF MASSACHUSETTS

Donald M. Anderson and Francois M.M. Morel

Recent research has linked the location, timing, and geographic spreading of toxic *Gonyaulax tamarensis* and *G. excavata* blooms on Cape Cod to the dormant overwintering cysts (hypnozygotes) of these species. In addition, variations in the trace metal speciation (and thus the toxicity) of coastal waters has been proposed as a second mechanism controlling the distribution of *G. tamarensis* populations. A model is presented here which synthesizes these and other recent developments and offers a coherent explanation of the historical pattern of shellfish toxicity in the region.

In Press: *Toxic Dinoflagellate Blooms. Proc.2nd Int'l.Conf. D.Taylor(ed.) Elsevier-North Holland,Inc.*

Supported by: *M.I.T. Sea Grant 04-7-158-44079; Internat.Copper Research Assoc. (Proj.#252); WHOI Ocean Industry Program.*

GROWTH LIMITATION OF A COASTAL DIATOM BY LOW ZINC ION ACTIVITY

Michael Anderson, Francois M.M. Morel and Robert R.L. Guillard

Recent measurements place the total zinc concentration in unpolluted marine waters to be in the 10^{-10}M range. Such low ambient concentration of an essential micronutrient invites one to consider the possibility of phytoplankton growth limitation by zinc. Although iron has long been considered as a potential limiting micronutrient in the marine environment, other trace metals necessary for phytoplankton growth have not. On the basis of laboratory work which focuses mostly on copper, it is well-known that the toxicity of a trace metal depends on its chemical speciation and can be related uniquely to its free ion activity. However, it has not been unequivocally established that the availability of some metals may also be controlled by their free ion activities and thus may be depressed by organic complexation. Here we report laboratory experiments demonstrating that the zinc ion activity (rather than the total zinc) concentration) limits the growth rate of a coastal diatom *Thalassiosira weissflogii* and that the limitation occurs at zinc ion activities that would be present in unpolluted seawater if any organic complexation of zinc were taking place.

Supported by: *NSF Grant OCE 76-10870.*

RECOVERY POTENTIAL OF PHYTOPLANKTON AFTER PASSAGE THROUGH COASTAL POWER PLANT ENTRAINMENTS

Joel C. Goldman and Helen L. Quinby

Natural populations of marine phytoplankton from the intake and discharge stations of two coastal power plants in southeastern Massachusetts all demonstrated the same degree of recovery when grown in laboratory continuous cultures on defined artificial seawater medium. Neither populations exposed to elevated temperatures or those subjected to chlorination and heat treatment showed any adverse permanent effects. The flora of phytoplankton species dominating in all samples for a particular experiment were consistently similar, indicating that alterations in the composition of phytoplankton species in receiving waters may be hardly measurable. It is concluded that entrainment effects on both phyto- and permanent zooplankton populations in receiving waters, beaause of their relatively rapid generation periods, are probably minor compared to the potentially major effects on larval plankton that spawn intermittently.

Supported by: *Contract from ERDA (now the Department of Energy) E(11-1)-2532).*

CHLORINE DISAPPEARANCE IN SEAWATER

Joel C. Goldman, Helen L. Quinby and Judith M. Capuzzo

A series of chlorination studies were carried out on natural and artificial seawater. It was determined that both the forward and back titration procedures accurately described the two phases of chlorine losses in seawater: a rapid initial loss followed by a continuous loss at a sharply reduced rate. The order of adding the iodide and buffer reagents was found to be crucial in affecting the rapid initial loss. The initial loss was found to reach a saturation level that varied widely between natural seawater samples and appeared to be related to a true organic demand. In contrast, the second phase was difficult to explain. Losses continued over 10-day periods and were pronounced in both natural and artificial seawater containing bromide. In the absence of bromide, long term losses in artificial seawater were greatly reduced, indicating that the lost applied chlorine was associated with the bromine chemical system in seawater. The fate of the lost chlorine was not determined and the untitratable halogen compounds must remain suspect

as potential biocides.

In Press: *Water Research.*

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

BIOLOGICAL AND GEOCHEMICAL INFLUENCES ON NUTRIENT CYCLING IN OCEANIC WATERS

Joel C. Goldman, James J. McCarthy, and Dwight G. Peavey

The chemical composition of oceanic phytoplankton (by atoms) typically is found in the proportions C_{106} N_{15} P_1. Yet, under laboratory growth conditions these proportions are only observed for marine phytoplankton at high growth rates when non-nutrient limitation is approached. One implication of these findings is that growth rates of natural phytoplankton populations in oceanic waters may be quite high and near or at nutrient saturation. The fact that biomass and residual nutrient levels in such waters are uniformly low does not preclude the possibility of high growth rates because zooplankton grazing and nutrient regeneration within the euphotic zone may keep this highly dynamic system in a balanced state. Another possible explanation for the consistency of phytoplankton chemical constituents is that early in geology history nitrogen and phosphorus entered the oceans in an approximate 15:1 ratio and phytoplankton through adaptation have been assimilating these nutrients in such proportions.

Supported by: *U.S.Dept. of Energy ET-78-S-02-4812; NOAA Sea Grant 04-8-MO1-149; NSF Grant OCE-78-19420.*

TEMPERATURE EFFECTS ON STEADY STATE GROWTH, PHOSPHORUS UPTAKE, AND THE CHEMICAL COMPOSITION OF A MARINE PHYTOPLANKTER

Joel C. Goldman

The marine cyrysophyte *Monochrysis lutheri* was grown in phosphorus-limited continuous cultures at temperatures of 15°, 18.8° and 23°C. The effect of temperature on the maximum growth rate was well-defined by the Arrenhius equation, but the Q_{10} for this alga (1.7) was somewhat lower than has been determined previously for many other phytoplankton species (2.0-2.2). The minimum phosphorus cell quota was relatively unaffected by temperature at 18.8°C and 23°C, but doubled in magnitude at 15°C. As a result, the internal nutrient equation of Droop described the relationship between specific growth rate and phosphorus cell quota well at 18.8° and 23°C, but was less successful at 15°C. The major limitation in using the Droop equation for any limiting nutrient is that the ratio between the minimum and maximum cell quotas must be known, thus necessitating the need to establish the true maximum growth rate by the cell washout technique. In addition, the phosphorus uptake rate on a cell basis at a given steady state growth rate (= specific uptake rate) increased dramatically at 15°C, whereas the rate of turnover of total available phosphorus was unaffected by temperature. Both the nitrogen and carbon cell quotas were relatively unaffected by growth rate at a given temperature, but increased slightly with decreasing temperature. The overall conclusion is that growth and uptake rates for a limiting nutrient are only synchronous at or near the optimum temperature for growth of *M. lutheri*. Because these types of responses are species specific, much additional data on temperature effects will be required before the importance of including such effects in phytoplankton-nutrient models can be determined.

Supported by: *NSF Grant OCE 78-19420.*

HYDROGEN FORMATION BY MARINE ALGAE

Elias Greenbaum, David Mauzerall and Robert R.L. Guillard

Several marine clones of *Chlamydomonas* evolved H_2 in light. No *Chlamydomonas* clone liberated H_2 in the dark. Neither light nor dark H_2 evolution occurred in the *Platymonas, Synechococcus marina, Thalassiosirs pseudonana, Amphidinium carterae,* nor *Chroomonas salina,* but *Oscillatoria* produced a little H_2 in darkness. Dark H_2 evolution also occurred in freshly collected *Chondrus crispus, Enteromorpha linza, Ulva lactuca, Codium fragilis, Ceramium rubrum,* and *Neoagardhiella baillevi,* but not in *Fucus vesiculosus* nor *Porphyra umbilicalis.* No macroscopic alga studies showed light-driven H_2 evolution. The implications of these findings are discussed.

Published in: *The Biological Bulletin, 155(2), p.441, October 1978.*

Supported by: *The Experimental Marine Botany Course; Technology Dept., Medical Products Div., Union Carbide Corp.; and NSF Grants BMS 74-11747 and OCE 78-08858.*

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 phytoplankton cells. This cannot be reversed, is asymmetric - since cells in decomposition cannot be productive of both nutrient and capacity to absorb, when capacity to absorb is part of any cell. Cells so produced can be maintained against the normal, oceanic, steady-state losses of predation and sinking. Or cells so produced can increase in abundance toward shore due to greater nutrient there and the capacity to absorb it. In order to have some cells be less abundant toward shore the scheme has a contradictory part wherein they are both present and not present. This contradictory part is expanded to having cells present, having something preventive of them, and having them then not present. This portrays the oceanic cell's shoreward decrease, because it must be first there to be secondarily prevented from being there.

Supported by: *W.H.O.I. Sponsored Research.*

'PLACE' IN ECOLOGY

Edward M. Hulburt

A comparison is made of distantly-placed phytoplankton cells and closely-packed mussels. In both instances there are empty places available to the individual organisms. In order to define 'empty', tne zero class of Boolean algebra is used; what is common to the class of organisms and the class of non-organisms is no discrete objects at all. No discrete objects at varying concentrations provide a delineation of empty places. This delineation brings out a baffling consideration, namely: it is hard to decide whether a mussel forcefully gets ahead by growing in an empty place - this is competition under the close-packed conditions - or whether a mussel retiringly gives up its place through death by predation - this is certainly not competition. This dilemma is accentuated when one perceives phytoplankton cells just as they are - changing via the ample emptiness around them.

Supported by: *NSF Grant GA-29300.*

A REFERENTIAL CONTEXT FOR DESCRIPTION OF PHYTOPLANKTON AND NUTRIENTS IN NEW YORK WATERS

Edward M. Hulburt and Nathaniel Corwin

A referential context is one in which environmental variables and responses to them by the phytoplankton cells are referred to the cells. The justification for such a context lies in avoiding the dilemma of which makes which change, when cells make nutrient less concentrated and nutrient makes cells more abundant. It is conceived that ample nutrient and a strong response, which is indicated by a large abundance of cells, are both productive of cells - of cells conceived as stripped of any response, of any attribute. Thence, in mid-summer close to New York there is a class of samples having cells, denoted by c, having an average of 6 µg.-at. nitrate N/liter very productive of cells, denoted by n, and having a strong response productive of cells, denoted by g - therefore c ng. But seaward from New York nitrate goes below 1 µg.-at. N/liter as if consumed by cells but reported here as being less productive of cells ($\bar{n}$) than near New York, so that the seaward samples compose a class denoted by c $\bar{n}$ g. But when different temperatures occur and different temperature responses occur, indicated by different species, a broader terminology is required: there are classes of samples having cells, having environmental variables preferred for or at least good for cells, and having responses preferred for or at least good for cells.

Supported by: *NSF Grant GA-29300.*

ATTRIBUTES OF THE PLANKTON FLORA AT BUSHEHR, IRAN

Edward M. Hulburt, Farideh Mahmoodian, Mary Tussell, Firuzeh Stalcup, Shahla Lalezary and Parviz Amirhor

The plankton flora on the northeastern coast of the Gulf of Persia was found to consist of many diatom species, the coccolithophores *Gephyrocapsa oceanica* and *Coccolithus huxleyi,* and the blue-green alga, *Trichodesmium thiebautii.* These are prevalent throughout the year and always at low concentrations, with an average maximum in January of 14463 cells/liter and minimum in June of 802/liter. Such comparative constancy suggests that the flora has the attributes of stability and dependability. The individual species fluctuates in a patternless, uncorrelated manner, so that the flora is characterized by a series of failures and recoveries of these species. The turbidity of the shallow water reduces the light so that light is usually neither limiting nor inhibitory. There is a small amount of nitrate always available and ample phosphate and silicate. Thus lack of constraint by light and nutrient would seem to be a necessary condition for the recoverability of the species. But pure culture studies of several species show little or no growth at 34°, and this temperature occurred in August of one of the two summers studied. Thus the recoverability of the plankton is an important attribute if a prolonged period of 34° occurs.

Supported by: *Eco-Zist Company, Tehran, Iran.*

AQUIL: A CHEMICALLY DEFINED PHYTOPLANKTON CULTURE MEDIUM FOR TRACE METAL STUDIES

Francois M.M. Morel, John G. Rueter, Donald M. Anderson and Robert R.L. Guillard

Precise chemical definition of the culturing medium is necessary for physiological studies of the effect of medium chemistry, particularly trace metal activities, on phytoplankton cells. The medium Aquil and its variations have been successfully used for trace metal studies of marine phytoplankton over the past three years. This artificial medium is designed to permit complete definition of chemical speciation of the various components. This is achieved by controlling trace element contamination, avoiding the formation of precipitates and adsorbates and calculating the thermodynamic equilibrium of the system. Here, the recipes, the methods of preparation and the chemical composition of Aquil are presented in detail. It is also established that Aquil is suitable for physiological experiments with a variety of marine phytoplankters representing all major phyla. Questions relating to modifications of the basic recipe and to the design of chemically defined media in general are discussed.

Supported by: *NSF Grant OCE 76-10876.*

DISTRIBUTION OF ELECTROMORPHS AND GROWTH-RATE CHARACTERISTICS IN ISOLATES OF Thalassiosira pseudonana *FROM THE NERITIC-OCEANIC BOUNDARY.*

Lynda S. Murphy, Robert R.L. Guillard, Hsueh-tze Lee and Larry E. Brand

The panthalassic diatom species *Thalassiosira pseudonana* consists of neritic and oceanic ecological races that have been characterized by electrophoretic banding patterns, physiological characteristics, and minor morphological differences. Here we compare clones of *T. pseudonana* recently isolated from the neritic-oceanic boundary with established clones from neritic and from oceanic waters. Results show that these new clones share characteristics with both the neritic and the oceanic races. They are not simple F_1 hybrids, and, unlike the neritic and oceanic races which are each highly homogeneous, there is much variability among these boundary clones. New clones from the outer shelf more closely resemble the neretic race, while new clones isolated from a warm core ring overlying the slope are more similar to the oceanic race. It appears that the boundary zone does not contain a distinct and homogeneous ecological race, but rather, it is a broad zone of hybridization between two races or semispecies.

Published in: *Journal of Phycology.*

Supported by: *NSF Grant OCE 76-10876.*

THE EFFECTS OF INDUSTRIAL WASTE ON MARINE PHYTOPLANKTON AT DEEP-WATER DUMPSITE 106.

Lynda S. Murphy, Peter H. Hoar and Rebecca A. Belastock

DuPont Grasselli waste was bioassayed using 16 clones in three species of marine phytoplankton. A bioassay system which allows the monitoring of growth under controlled conditions is described. Using this system, we have determined that low doses of waste stimulate growth; higher concentrations are inhibitory. The crossover point occurs in culture at approximately the highest concentration that is sustained in the environment. Clones from polluted estuaties are more sensitive to the waste than are clones of the same species from other environments. Long-term culturing may alter the physiological responses of some clonal cultures.

Supported by: *NOAA Grant 04-8-MO1-41.*

BIOCHEMICAL TAXONOMY OF MARINE PHYTOPLANKTON BY ELECTROPHORESIS OF ENZYMES. II. LOSS OF HETEROZYOGOSITY IN CLONAL CULTURES OF THE CENTRIC DIATOMS Skeletonema costatum *AND* Thalassiosira pseudonana.

Lynda S. Murphy

An electrophoretic survey of 12 new isolates of *Thalassiosira pseudonana* Hasle and Heimdal and 25 new isolates of *Skeletonema costatum* (Grev.) Cleve revealed several heterozygote genotypes at malate dehydrogenase (MDH) and phosphohexose isomerase (PHI) Loci. The new clones were maintained in culture for six months and then reassayed at these two loci. All MDH heterozygotes and half of the PHI heterozygotes had become homozygous. This resulted in a collection of clones that are largely homozygous but that are samples of polymorphic species. The physiological implications of the loss of heterozygosity in clonal cultures has not been analyzed. However, any change in a clone that is the result of culturing conditions reduces the usefulness of that clone as a laboratory test organism for ecological correlations.

Published in: *Journal of Phycology.*

Supported by: *NSF Grant OCE 76-10876 and NOAA Grant 04-7-158-44056.*

NITROGENOUS NUTRITION OF MARINE PHYTOPLANKTON IN NUTRIENT DEPLETED WATERS

James J. McCarthy and Joel C. Goldman

Variability in small scale temporal and spatial patterns in nutrient supply, coupled with enhanced nutrient uptake capability induced by nitrogen limitation, permit phytoplankton to maintain near maximal rates of growth at media nutrient concentrations which cannot be quantified with existing analytical techniques.

Supported by: *NSF Grants OCE 75-14781, and OCE 77-26401 and ERDA Contract E(11-1)-2532.*

PERIODICITY OF CELL DIVISION IN 26 PLANKTONIC MARINE ALGAE GROWN ON LIGHT-DARK CYCLES

David M. Nelson and Larry E. Brand

The division rates of clonal cultures of 26 planktonic marine algae, during exponential growth on a 14:10 hr light:dark cycle in nutrient-replete batch cultures, were determined every two hours for 48 hours. Cyclic oscillations in the division rate were detectable in 22 of these clones. The 14 diatoms examined displayed either near-constant division rates throughout the light: dark cycle (4 clones) or strong periodicity favoring division during the light period (10 clones). In contrast, all other algae (12 clones) exhibited division rate maxima during periods of darkness, and clearly detectable decreases in cell number for time intervals of 4-8 hr during periods of illumination. Intraspecific differences in division periodicity were found among 8 clones of the diatom *Thalassiosira pseudonana* and 6 clones of the coccolithophore *Emiliania huxleyi*.

Supported by: *NSF Grant GB 33288, WHOI Postdoctoral Fellowship and NSF Graduate Fellowship.*

THE IMPORTANCE OF SILICON IN MARINE EUTROPHICATION

Charles B. Officer and John H. Ryther

Diatom phytoplankton populations are the usual food for zooplankton and filter fishes and contribute in a direct way to the large fishable populations in coastal zones. Flagellates, on the other hand, are frequently poor foods for most grazers and can lead to undesirable eutrophication effects. Arguments are presented that silicon is often the controlling nutrient in altering a diatom to a flagellate community. The alteration is governed by the relative magnitudes of the natural fluxes of the nutrients nitrogen, phosphorus and silicon to the receiving water body and the recycled fluxes of nitrogen and phosphorus from zooplankton grazing and phytoplankton respiration and decomposition. Examples of such alterations are presented for oceanic, estuarine and inland water bodies.

HARVEST OF MARINE MICROALGAE BY CENTRIFUGATION IN DENSITY GRADIENTS OF "PERCOLL", A MODIFIED SILICA SOL.

Ellen M. Reardon, Carl A. Price and Robert R.L. Guillard

Naked dinoflagellates, other fragile flagellates, diatoms and a species of blue-green bacterium have been recovered physiologically active and structurally intact after centrifugation into density gradients of "Percoll", in a synthetic seawater based on sorbitol. This medium is comparable with "Percoll", a polyvinyl pyrrolidone-modified silica sol, over a spectrum of saline and magnesium concentrations typical of those found *in situ*. Isopycnic sedimentation of the test organisms into this gradient resulted in the concentration and resolution of the algae in narrow bands, whose densities were specific to each species examined. Both continuous and step gradients were tested, the continuous gradient being linear between a starting density of $\rho = 1.03$ to a terminating density of $\rho = 1.15$. Intactness of the microorganisms was judged by comparing microscopic appearance and motility before and after density gradient centrifugation and after pelletting of the algae. The successful collection of nanoplankton, including some of its most elusive and delicate representatives, has broad implications for the study of the physiology of marine microalgae.

Published in: *Methodological Surveys in Biochemistry, 8, Eric Reid, ed. 1979.*

Supported by: *NSF Grant OCE 77-10876.*

TIDAL RESUSPENSION IN BUZZARDS BAY, MASSACHUSETTS. I. SEASONAL CHANGES IN THE RESUSPENSION OF ORGANIC CARBON AND CHLOROPHYLL A.

Michael R. Roman and Kenneth R. Tenore

Greater than 50% increases in the amount of particulate organic carbon and chlorophyll *a* per square meter occurred in a 13-m water column of Buzzards Bay during tidal cycles. The composition and quantity of the resuspended material varied seasonally. Greater percentages of the carbon in the water column were resuspended during the summer and winter months while more resuspension of chlorophyll *a* occurred during spring and summer. Increases

in the amount of primary production in the water column occurred with the resuspension of Chlorophyll *a*, indicating that the resuspended cells were viable. The contribution of this resuspended phytoplankton to the total yearly primary productuvity can be significant.

The tidal resuspension of phytoplankton and detritus from the mud bottom of Buzzards Bay, if utilized by the zooplankton community, could provide significant food resources for secondary production.

Published in: *Estuarine and Coastal Marine Science, 6:37-46, 1978,*

Supported by: *NSF Grant GA-39911 and NSF Doctoral Dissertation Fellowship DES 75-10025.*

TIDAL RESUSPENSION IN BUZZARDS BAY, MASSACHUSETTS. II. SEASONAL CHANGES IN THE SIZE DISTRIBUTION OF CHLOROPHYLL, PARTICLE CONCENTRATION, CARBON AND NITROGEN IN RESUSPENDED PARTICULATE MATTER

Michael R. Roman

Seasonal changes in the particle size spectrum of suspended matter in near-bottom water of Buzzards Bay was studied by fractional filtration. The greatest fraction of the total particulate organic carbon and particulate organic nitrogen throughlut the year was less than 20 µm. The relative independence of the seasonal size distribution of particulate carbon to changes in the chlorophyll, as well as high carbon:nitrogen ratios during winter, suggest that large amounts of detritus are present in Buzzards Bay. Chlorophyll *a* distribution was dominated by nanoplankton in the spring and summer months when inorganic nutrients were low and zooplankton grazers abundant. The winter and fall phytoplankton blooms were dominated by individual and chain-forming diatoms greater than 53 µm. The dominance of nanoplankton and nanodetrirus (<20 µm) in the suspended matter of Buzzards Bay suggests that the major source of nutrition for filter feeding zooplankton are small particles.

Published in: *Estuarine and Coastal Marine Science, 6:47-53, 1978.*

Supported by: *NSF Grant GA-39911 and NSF Doctoral Dissertation Fellowship DES 75-10025.*

SALT MARSHES

HEAVY METAL UPTAKE IN A NEW ENGLAND SALT MARSH

Anne Giblin, Alain Bourg,
Ivan Valiela and John M. Teal

The study involved the cycling of heavy metals in Great Sippiwissett Marsh as part of an investigation on the potential of salt marshes to act as natural waste treatment systems by adding varying doses of sludge-containing fertilizer to experimental plots. Marsh sediments retained 20-35% Cd, 20-50% Cr, 60-100% Cu, 55-100% Pb, 80-100% Fe, 55-60% Mn and 20-45% of the Zn added in the fertilizer. Except for Mn, high marsh areas retained a significantly greater fraction of the added metals than low marsh. The difference in redox potential of the two areas could be partly controlling metal retention.

Supported by: *Victoria Foundation and NOAA Sea Grant 04-7-158-44104.*

THE ENVIRONMENTAL IMPACT OF INDUSTRIAL ENERGY SYSTEMS IN THE COASTAL ZONE

Charles A.S. Hall, Robert Howarth,
Berrien Moore III, and Charles J. Voresmarty

The possible environmental effects of energy systems in the coastal zone (principally oil-related facilities and electric power plants) are surveyed, and the literature dealing with such effects is reviewed. The use of the coastal zone for energy-related facilities is increasing rapidly, and the potential for wide-spread damage to biological resources is large. Oil-related facilities (oil refineries, storage areas, offshore rigs) have a particularly high potential for causing damage.

Supported by: *WHOI Predoctoral Fellowship.*

A NO.2 FUEL OIL SPILL IN BOURNE, MASSACHUSETTS: THE IMMEDIATE ASSESSMENT OF THE EFFECTS ON MARINE INVERTEBRATES AND A THREE-YEAR STUDY OF GROWTH AND RECOVERY OF A SALT MARSH.

George R. Hampson and Edwin T. Moul

On October 9, 1974 the oil barge *BOUCHARD 65* loaded with 73,000 barrels of oil spilled what was initially thought by the Coast Guard to be a few barrels and later raised to an undetermined amount of #2 fuel oil off the west entrance of the Cape Cod Canal in Buzzards Bay, Massachusetts (anchor site "C", Fig.1). Within the following two-week period, oil from the barge was found contained along the west side of Bassetts Island and inner Red Brook Harbor, a distance of 5.0 km from the site of the spillage. Qualitative samples of dead and moribund marine invertebrates were

collected in tide pools and slight depressions along the beaches. A collection consisting of 4,360 invertebrates comprising 110 species, plus two species of fish were found in eight samples. Noticeable effects were also observed.

A detailed quantitative examination was begun to determine the effects of the oil on various components of the affected salt marsh community in Winsor Cove compared to a selected control site. From data collected in September 1977, the marsh grass in the lower intertidal zone in Winsor Cove has shown an inability to reestablish itself either by reseeding or rhizome growth. The associated sediments show a correspondingly high concentration of petroleum hydrocarbons impregnated in the peat substrate. Erosion rates measured in the effected area, as a result of the three year period of marsh degeneration, were 24 times greater than the control site.

Microscopic algae were collected during the sampling period and those present were considered least sensitive to environmental changes. Examination of the interstitial fauna found in the study area in the summer of 1977 showed an extremely reduced number of individuals and species.

Supported by: *NOAA Sea Grant 04-6-158-44-106.*

THE RAPID FORMATION OF PYRITE IN A SALT MARSH AND ITS IMPORTANCE TO ECOSYSTEM METABOLISM

Robert W. Howarth

Large amounts of pyrite (FeS_2) are formed in salt marsh sediments on a time scale of a day or less. This contradicts the generally-held belief that pyrite forms only very slowly in natural sediments from iron monosulfides (FeS). Even though pyrite is more stable than iron monosulfides, in most anoxic marine sediments iron monosulfides form first for kinetic reasons. But in the salt marsh peat, iron monosulfides are undersaturated while pyrite is supersaturated, so the formation of pyrite is quite rapid. If this rapid formation of pyrite is ignored, rates of sulfate reduction can be grossly underestimated. When pyrite is included in measurements of sulfate reduction, it is seen that sulfate is the major electron acceptor for respiration in a New England salt marsh ecosystem, being more important than oxygen or nitrate.

Supported by: *NSF Grant DEB 76-83877 and WHOI Predoctoral Fellowship.*

DENITRIFICATION IN A SALT MARSH EXOSYSTEM

Warren Kaplan, Ivan Valiela, and John Teal

The rate of denitrification was measured throughout the year in various habitats of a New England salt marsh. The rates were correlated to temperatures and were highest in the wettest habitats. Over 60% of the denitrification took place in the muddy creek bottom. Annual denitritification exceeds nitrogen fixation. An amount of nitrate similar to the quantity consumed by denitrifiers is supplied by the flow of ground water into the marsh and by nitrifiers within the marsh itself.

Supported by: *NSF Grants GA-41506, GA-43008, and GA-43009.*

NITROGEN FIXATION BY RHIZOSPHERE AND FREE-LIVING BACTERIA IN SALT MARSH SEDIMENTS

John M. Teal, Ivan Valiela, and Diana Berlo

The rates of nitrogen fixation by rhizosphere and free-living bacteria are highest near the surface of a variety of salt marsh sediments and in the warm part of the year. The highest rates were found in vegitated habitats, reaching up to about 500 ng $N \cdot cm^{-2} \cdot h^{-1}$. Bacterial N_2 fixation for the entire marsh is more than 10 times larger than algal fixation and less than a third of the N required to support growth of the vegetation.

Published in: *Limnology and Oceanography, 24:126-132.*

Supported by: *NSF Grants GA-43008 and GA-43009.*

ENRICHMENT IN COASTAL WETLANDS

John M. Teal and Ivan Valiela

Sewate fertilization of coastal salt marshes results in increased primary production which is followed by increases in populations of herbivores, detritivores, and predators. Sediments bind metals in place though there is increased plant uptake.Coastal marshes may be useful as components of waste-water treatment systems.

Supported by: *NOAA Sea Grant 04-6-158-44-106, Victoria Foundation, Applied Oceanography Program, WHOI, A.B.Clifford and Salt Pond Association.*

WATER RESOURCES AND RENOVATION

THE WATER TABLE OF CAPE COD

Alfred C. Redfield

In summary the elevation of the water-table does not indicate the quantity of fresh water which is available for human use, which depends in the long run on the quantity of precipitation minus the losses which occur from evaporation, transpiration, flow to the sea and human use. Its elevation depends on the local character of the soil and provides a surplus to meet the needs of temporary variations in precipitation and use. Its continued fall indicates that the losses are in excess of the gains and if continued may lead to the invasion of salt water into the water supply. Its slope indicates the direction which flow to the sea will take and shows the direction in which local sources of pollution may be expected to spread.

WASTEWATER RENOVATION AND RETRIEVAL ON CAPE COD

Ralph F. Vaccaro, Peter E. Kallio, Bostwick H. Ketchum, William B. Kerfoot, Alicja Mann, Patricia L. Deese, Carl Palmer, Mark R. Dennett, Paul C. Bowker, Nathaniel Corwin and Steven Manganini

A rapidly increasing population on maritime Cape Cod has generated considerable interest in alternative wastewater disposal techniques which promise to maintain high groundwater quality and promote its conservation. Such deliberations, five years ago, led us to undertake an assessment of agricultural spray-irrigation as a potential means of lessening groundwater contamination and depletion. In the course of these studies individual components of an entire wastewater-cropping facility have been isolated and subjected to detailed examination. Experimental emphasis has been placed on variations in the rates and methods of wastewater application and in the types of renovative agricultural crops placed under wastewater irrigation.

Results from these studies have been highly promising and suggest that under ideal circumstances, the coupling of secondary domestic effluent to animal forage crops can bring about a degree of wastewater renovation which exceeds direct disposal to sand filter beds and approaches the goals of tertiary treatments. Moreover, three desirable consequences, i.e., water conservation, crop irrigation and nourishment and wastewater renovation are simultaneously achievable. Further confirmation and extentions of these results could mean an elevation of domestic wastewaters into the category of a significant natural resource.

Geologically, Cape Cod is viewed as a glacial outwash plain connected to a series of drown river valleys. The local geohydrology features several hundred feet of glacial till overburdening a deep basement rock, a condition ideally suited for wastewater irrigation. Also available is a considerable amount of undeveloped acreage which could be committed to wastewater recycling. The soil is generally sandy and poor in an agricultural sense, yet usage and conditioning has resulted in dry forage grass yields in excess of 8.9 metric tons (4 short tons) per hectare per year.

Relative to crop requirements, there is characteristically an excess of phosphorus over nitrogen in most secondary effluents. However, excess phosphorus which the plants are unable to utilize is readily bound within the uppermost foot of soil. A similar fate is accorded unassimilated heavy metal ions which are also stabilized within the soil and denied access to underlying groundwater. Distinct from the above behavior, other chemical elements of secondary effluent such as chloride, sodium, potassium and boron have been observed to penetrate the groundwater to a considerable extent. The ultimate impact of such penetration has not been fully resolved.

Supported by: *E.P.A. and Commonwealth of Massachusetts S-802037.*

ZOOPLANKTON

THE EFFECTS OF HALOGEN TOXICANTS ON SURVIVAL, FEEDING AND EGG PRODUCTION OF THE ROTIFER Brachionus plicatills

Judith M. Capuzzo

The toxicity of free chlorine and combined chlorine as chloramine to the rotifer *Brachionus plicatilis* at three exposure temperatures has been evaluated. Chloramine was more toxic to rotifers than the free halogen form with LC_{50} values for 30-minute exposures at 20°C of 0.35 mg/l applied chloramine and 1.20 mg/l applied free chlorine, 0.02 mg/l and 0.18 mg/l residual levels, respectively. The synergistic effect of temperature on the toxicity of both halogen forms was also noted. Rotifers surviving exposure to either halogen toxicant had significantly lower filtration rares and egg production rates than control animals. The reduced reproductive rates were not sustained by the second generation of rotifers and it appears that exposure to free chlorine or chloramine does not result in a permanent alteration in the reproductive potential of rotifer populations.

In Press: *Estuarine and Coastal Marine Science.*

Supported by: *DOE Con.EY-76-S-02-2532.*

TIDALLY-GENERATED INTERNAL WAVE PACKETS IN MASSACHUSETTS BAY, U.S.A.: PRELIMINARY PHYSICAL AND BIOLOGICAL RESULTS

Loren R. Haury, Melbourne G. Briscoe, Marshall H. Orr

Obserfations in Massachusetts Bay of high-frequency internal wave packets indicate they are caused by lee waves generated outside a submarine bank at the Bay's seaward margin during ebb tide. The lee waves propagate into the Bay as the tide turns to flood, steepen nonlinearly, and develop into a packet. A 200 kHz acoustic backscattering system detected the evolution of the packets. Large overturning events were observed acoustically and in density profiles. Plankton distributions undergo strong vertical displacements and mixing associated with the wave packet passage.

Supported by: *NSF Grant OCE-77-08682.*

PLANKTON AND INTERNAL WAVES: THE MASSACHUSETTS BAY EXPERIMENT

Loren R. Haury, Melbourne G. Briscoe and Marshall H. Orr

Every 12.4 hours, groups of short-period internal waves propagate southwestward across Massachusetts Bay from Stellwagen Bank (silt depth 25 m). These waves have a period of 6-8 minutes, amplitudes of up to 30 m, and a group velocity of about 60 cm/sec. Preliminary results suggest the waves are generated by the blocking action of Stellwagen Bank on the barotropic semidiurnal tide outside the Bank as it turns to the flood (southwest) flow) stage. The warm surface waters to the east apparently spill across the Bank forming a depression in the thermocline which propagates southwestward, nonlinearly steepening on its front face, and developing undulations behind it. Within the Bay (82 m maximum depth), the thermocline deepening averaged about 10 m immediately after the wave packet arrival and gradually decreased during the next 12.4 hours. The waves decay in the nearshore region (20 to 30 m depths). Physical, biological, and acoustic (200 kHz) data all show mixed events due to internal wave breaking on vertical scales of from centimeters to about 15 m. The biological effects of the internal waves are significant: (1) there is potential for nutrient input to the surface waters from subthermocline depths in mid-bay and from sediments in the nearshore decay zone; (2) the subsurface chlorophyll maximum at 10 m before wave arrival deepens by an average of 10 m for periods of 6-8 hours; (3) both phytoplankton and zooplankton are mixed by breaking events, with the resultant vertical and horizontal redistribution of initially stratified populations. These results suggest that the satellite-observed internal waves present over much of the world's continental shelf regions may also be of biological importance.

Published in: *American Society of Limnology and Oceanography, Inc.*

Supported by: *NSF Grant OCE-77-08682.*

THE EFFECT OF TEMPERATURE ON THE TOXICITY OF CHLORINATED COOLING WATERS TO MARINE ANIMALS - A PRELIMINARY REVIEW

Judith M. Capuzzo

The effect of temperature on the toxicity of free chlorine and chloramine to several species of marine animals is reviewed. For all species tested, except the copepod *Acartia tonsa,* temperature has a synergistic effect on the toxicity of both halogen forms. It is suggested that the effect of temperature in enhancing the toxic effects of chlorinated cooling waters to marine animals is due to an interaction of uptake rates and regulation of physiological rates and the greatest enhancement in sensitivity could be expected at the upper limit of a species' thermal tolerance.

In Press: *Marine Pollution Bulletin*

Supported by: *D.O.E. Contract EY-76-S-02-2532.*

LARVAL DEVELOPMENT IN THE AMERICAN LOBSTER: CHANGES IN METABOLIC ACTIVITY AND THE O:N RATIO

Judith M. Capuzzo and Bruce A. Lancaster

The rates of oxygen consumption under conditions of feeding and starvation and the rates of ammonia excretion after feeding increased with each larval stage and decreased with the first postlarval stage of the American lobster. There was no significant difference in the O:N ratio of the first three larbal stages ($\sim$26.5), but a significant reduction ($P<0.01$) was measured among stages IV and V. It appears that, whereas protein catabolism may be the principal source of energy, some of the energy yield during larval development is from lipid or carbohydrate catabolism; the use of the latter substrates is diminished in the last larval and the first postlarval stage.

Supported by: *NOAA Sea Grant 04-7-158-44104.*

SOME PHYSIOLOGICAL AND BIOCHEMICAL CONSIDERATIONS OF LARVAL DEVELOPMENT IN THE AMERICAN LOBSTER, Homarus americanus

Judith M. Capuzzo and Bruce A. Lancaster

The weight specific respiration rates of fed and starved lobsters and the ammonia excretion rates of fed lobsters increased with each larval stage (I through IV) and decreased with the first postlarval stage (V). The rate of change in metabolic rates was greater than the rate of change of body size of the larval stages, indicating an increased energy demand of the later larval stage. There was no significant difference in the O:N ratio for the first three larval stages but a reduction was observed in stage IV and V lobsters, reflecting an increased dependence on protein catabolism for energy.

Protein was the principal biochemical constituent of all lobster stages. Significant decreases in lipid content and increases in ash and chitin content of the last larval (IV) and first postlarval (V) stages were detected.

Supported by: *NOAA Sea Grant 04-7-158-44104.*

THE EFFECTS OF DIETARY CARBOHYDRATE LEVELS ON PROTEIN UTILIZATION IN THE AMERICAN LOBSTER (Homarus americanus)

Judith M. Capuzzo and Bruce A. Lancaster

The protein-sparing action of dietary carbohydrate levels in artificial diets for the American lobster has been investigated. The artificial diets were pelletized shrimp meal based diets varying in both protein content (16.6-23.3%) and carbohydrate content (22.9-31.3%) and the protein:carbohydrate ratio (0.5-1.0). Respiration rates, ammonia excretion rates, O:N ratios and protein efficiency ratios of postlarval lobsters fed the various artificial diets were compared with lobsters fed a brine shrimp diet (*Artemia salina;* 51% protein, protein:carbohydrate ratio = 5.1).

Respiration rates measured immediately after feeding were highest among the brine shrimp-fed lobsters and were 37% higher than the standard respiration rates measured 24 hours later. The increased rate of oxygen consumption associated with feeding is termed the specific dynamic action (SDA) and reflects the calorigenic effect of protein catabolism. The values for SDA from lobsters fed the three artificial diets were not significantly different from one another and were ~17% higher than the standard respiration rate. There was no significant difference in standard respiration rates of lobsters from the four test groups.

Ammonia excretion rates of lobsters fed the three artificial diets and the brine shrimp diet were significantly different from one another and were directly correlated with the protein level of each diet. The O:N ratio (atomic ratio of oxygen consumed:ammonia-N excreted) and protein efficiency ratio (Δgrams/grams protein consumed) for each group were inversely correlated with the protein level of the four diets. For brine shrimp fed lobsters, an O:N ratio of 12.9 was measured, indicating a high dependency on protein catabolism as an energy source; the protein efficiency ratio of this group of lobsters was 2.9. For lobsters fed the three artificial diets, the O:N ratio ranged from 16.2 to 23.3 and the protein efficiency ratio ranged from 6.2 to 7.5. The increase in the O:N ratios and protein efficiency ratios with decreasing protein levels in the artificial diets provides a strong indication of the increased dependency on dietary carbohydrate as an energy source in postlarval lobsters.

Published for: *World Mariculture Soc., Meetomg om Jawaoo. Kam/22-26.1979/*

Supported by: *NOAA Sea Grant 04-7-158-44104.*

ORIGINS OF OCEANIC PLANKTON IN THE MIDDLE ATLANTIC BIGHT

James Cox and Peter H. Wiebe

Expatriated species of zooplankton found in the Mid-Atlantic Bight include Arctic-Boreal species derived from shelf waters northeast of Cape Cod, transition zone species from the adjoining Slopw Water and tropical-subtropical species that commonly reside in the Gulf Stream and Sargasso Sea. Introduction of expatriates is largely associated with the pattern of advective movements of water onto the shelf: Arctic-Boreal species are brought in from the northeast largely by storm-driven transport; transition zone species by Slope Water penetration at the surface when horizontal density gradients are minimal and at mid-depth in response to physical processes such as estuarine type-circulation, wind-driven upwelling, cold shelf water "bubble" formation and movement out into the Slope Water or to shelf-Slope Water interactions associated with warm core rings; warm water species by injection of warm core ring surface water in over the shelf. There is little evidence that Carolinian species are introduced into the Mid-Atlantic Bight directly around Cape Hatteras. In general, the occurrence of expatriate warm water species is more important in terms of species numbers and total biomass when compared to the occurrence of expatriate cold water species. The Bight region can be divided into three regions with regard to oceanic influences.

1) the band of low salinity water along the coast south of the mouth of the Hudson River, extending to the mouth of the Chesapeake; 2) the Continental Shelf edge extending from about 37°30'N to 40°N and extending shoreward towards the eastern half of the Long Island and Block Island Sound, but not including the region southeast of Cape Cod and Nantucket; 3) the southern sector, including the shelf edge south of 37°N and extending landward south of Chesapeake Bay. Each of these regions is characterized by types of expatriate species and by hydrographic features.

A mechanism is postulated whereby warm water species which cannot withstand harsh winter conditions in the mid-Atlantic Bight can "over-winter" by the movement offshore of adults or larvae in shelf water entrained at Cape Hatteras in late summer or early fall, by transit alongside or within the Gulf Stream, by incorporation into a warm core ring and by return to shelf waters in the spring when the ring impinges on the shelf margin.

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

MACROZOOPLANKTON AND ITS ENVIRONMENT

Richard L. Haedrich and David C. Judkins

Understanding the distributions of pelagic animals has traditionally been sought in correlation with physical properties of the ocean. Thus, the oceanic zoogeographer has been sensitive to the distribution of temperature and salinity, the water masses, oceanic circulation, and the more directly biologically important variables of oxygen, light, and nutrients. Monographic studies have given way to computer-based community analyses, but, while the ability to measure certain properties has been greatly refined, the basic concepts in oceanic zoogeography have changed but little since the work of early investigators. Oceanic species are very widespread, and intraspecific variation and endemism are both low. Faunal regions are large, semi-enclosed, monotonous, stable, old, and few in number. They are tuned to the climate. Faunal changes tend to occur rather gradually over considerable distance. The shapes of animal distributions appear to be the same as those for physical properties, especially the latitudinal pattern displayed by temperature. Expatriation is probably common in the ocean and has important consequences for speciation, but more studies of larval distributions and life histories are needed. Oceanic communities are defined through the co-occurrence of species in collections, but over the range of the constituent species responses to changing physical parameters may vary quite differently. The resultant pattern is one of a constantly reordered mosaic, and it may thus be more a matter of convenience than of reality to speak of oceanic communities.

Published in: *Chap.II in van der Spoel and Pierrot-Bults (eds.), Zoogeography and Diversity in Plankton. Bunge, Utrecht.*

Supported by: *NSF Grant OCE 76-21878.*

THE FILTER-FEEDING RATES AND PARTICLE RETENTION EFFICIENCIES OF THREE SPECIES OF CYCLOSALPA (TUNICATA, THALIACEA)

G. Richard Harbison and Vicki L. McAlister

The particle retention spectra of the mucous nets of three species of salps were determined by monitoring differences in grazing rates on particles of different sizes with a Coulter Counter. It is pointed out that the only correct method for determining these spectra for an organism feeding in a closed vessel is to compare rates of clearance for each particle size class; if only initial and final concentrations are measured, incorrect retention spectra will be produced. *Cyclosalpa floridana, C. affinis* and *C. polae* can all remove particles approximately four microns in diameter and larger with 100% efficiency. Differences between species in the retention characteristics of the filtration apparatus are observed, but these differences can be ascribed to differences in the sizes of the animals. In general, smaller salps can retain a greater fraction of small particles than can larger ones. Although quantitative differences in the particle retention spectra between generation and species exist, there is little evidence that qualitative differences are also present. Depending on the abundance of these salps, their grazing impact on particles with diameters as small as one micron could be significant.

Supported by: *NSF Grant DES 75-21715 and NOAA Grant 04-6-158-44072.*

EFFECTS OF TEMPERATURE ON THE SWIMMING OF SALPS (TUNICATA, THALIACEA): IMPLICATIONS FOR VERTICAL MIGRATION

G. Richard Harbison and Robert B. Campenot

Since there is growing evidence that some salps vertically migrate over a considerable range, effects of temperature of the swimming of salps were investigated. In most cases, the swimming rhythms of individual salps were remarkably regular at constant temperature. However, a few species showed irregular patterns. There is an inverse relationship between pulsation rate at constant temperature and body length for hand-collected

animals, but it was found that collection with a horizontally-towed net destroyed this relationship and caused variable depression in the pulsation rate. Thus, organisms collected with these nets appeared damaged, and physiological data from them must be considered highly suspect. When temperatures were lowered experimentally, marked differences in the responses of individual salps were observed. Three artificial types were devised to characterize these responses. Type I salps showed a marked depression of the pulsation rate as the temperature was lowered. Q_{10} values were always greater than 1.4, and these salps eventually stopped swimming altogether. All individuals in the species, *Pegea confererata, Cyclosalpa polae,* and *Salpa cylindrica*, showed Type I responses. Salps showing the Type II and Type III responses differed from those showing the Type I response, in that they did not cease swimming at low temperatures, even when held there for long periods of time. Type II individuals had Q_{10} values greater than 1.4, and Type III individuals had Q_{10} values less than or equal to 1.4. The correspondence between response type and species group was not as clear-cut as with the species showing Type I behavior. *Salpa maxima* and *Cyclosalpa affinis* generally showed the Type II response. Individuals of *Salpa fusiformis* showed Type II and Type III responses equally. Only *Salpa aspera* generally gave the Type III response. *Iasis zonaria* showed Type III behavior, but this was coupled with an extremely irregular swimming rhythm. It is perhaps significant that the last three species are seldom collected in surface waters during the day. Based on observed temperature responses, it appears that these species are capable of making rapid vertical migrations to great depths. It is speculated that the differences observed in the temperature response reflect adaptations to differing modes of life in the open sea.

Supported by: *NSF Grant OCE 75-21715 and NIH Training Grant NS-7009.*

EXPERIMENTAL EVALUATION OF THE ESCAPE REACTION OF Calinus finmarchicus

Loren R. Haury, Douglas E. Kenyon, and James R. Brooks

The escape reaction of *Calanus finmarchicus* copepodites was investigated using an apparatus allowing quantification of the fluid mechanical signals which might elicit the reaction. The copepods were in a rotating cylinder of sea water with fixed obstacles (diameters of 6 and 19 mm) acting to disturb the flow and stimulate avoidence. The experimental conditions prevented unambiguous discrimination of signals; fluid deformation and/or deformation rates appear to be the two most likely stimuli. The mean distance from the obstacle center where avoidence reactions were initiated was about 11 mm; animals were slightly closer to the large obstacle before avoiding. Mean values for fluid deformation for the small and large obstacles, respectively, were .12 and .24 mm/mm; fluid deformation rate values were .80 and 1.0 sec^{-1}. There was less scatter for deformation values. Animals preferentially avoided obstacles at an angle of about 60° with respect to the stagnation streamline. Avoidance speeds averaged 16 cm/sec; distance of avoidance flights averaged 15 mm.

Supported by: *WHOI-NIH Biomedical Res. Support Grant Seed Fund Program and NOAA Sea Grant 04-7-158-44104.*

RELATIONSHIPS BETWEEN OCEANIC EPIZOOPLANKTON DISTRIBUTIONS AND THE SEASONAL DEEP CHLOROPHYLL MAXIMUM IN THE NORTHWESTERN ATLANTIC OCEAN

Peter B. Ortner and Peter H. Wiebe

The potential significance of the Deep Chlorophyll Maxima (DCM) as a food resource for pelagic food chains was studied in three hydrographic regimes of the Northwestern Atlantic Ocean: the Slope Water, the Northern Sargasso Sea and a Gulf Stream cold core ring. Samples for phytoplankton species, chlorophyll and related water chemistry were obtained with a series of water-bottle casts from the upper 200 mi; microzooplankton and macrozooplankton were also obtained in the upper 200 m with Clarke Bumpus (67 mμ mesh) and MOCNESS (333 mμ mest) net systems. Samples were obtained in the summer when the DCM was well-developed and in the fall when mixing had erased the DCM in most areas.

Total zooplankton biomass was significantly enhanced within depth intervals including or adjacent to the seasonal thermocline in the three hydrographic areas. Hydrocast data show the DCM in these regions was predictably associated with the seasonal thermocline. Thus these data indicate zooplankton biomass was enhanced about the DCM when it was present.

In some cases, the zooplankton assemblage at DCM depths was distinguishable from those both at deeper and more shallow depths. The relative abundance of herbivorous functional groups which predominated at the DCM could be related to the size of the phytoplankton cells at DCM depths in the different environments. In addition to herbivorous zooplankton types, a purely carnivorous group, the chaetognaths, aggregated at DCM depths on occasion.

Overall, in environments from moderately rich near-shore Slope Waters to the more

oligotrophic open-ocean Sargasso Sea, our data suggest that the DCM signals a depth zone of particularly intense trophic activity.

Supported by: *ONR Contracts N00014-66-C-0241:NR 083-004; N00014-84-C-0262:NR-083-004; NSF DES 74-02783A1; WHOI Grad.Ed.Program and Tai Ping Foundation.*

CHEMISTRY

DEPARTMENT OF CHEMISTRY

Geoffrey Thompson, Chairman

ORGANIC AND BIOLOGICAL CHEMISTRY

VOLATILE ORGANIC COMPOUNDS IN COASTAL SEAWATER: PRELIMINARY RESULTS

Rene P. Schwarzenbach, Richard H. Bromund, Philip M. Gschwend and Oliver C. Zafiriou

The occurrence and temporal variations of a variety of low to medium polarity organic compounds in the volatility range bracketed by n-heptane and n-octadecane have been studied in seawater from a station in Vineyard Sound, Massachusetts, and from a tidal creek in Sippewisset Marsh, Massachusetts. The closed-loop vapor phase stripping method of Grob and Zurcher (1976), high resolution glass capillary gas chromatography, and gas chromatography-mass spectrometry were used. Approximately 50 compounds were found at $\geq$ 2 ng/kg; most were recovered at less than 10 ng/kg, while the 50 ng/kg level was only rarely exceeded by a few components. The total material recovered was 0.2-1.0 µg organic carbon equivalent/kg seawater. The major compound classes found were normal alkanes, alkenes, aromatic and alkyl-aromatic hydrocarbons, n-aldehydes, dimethyl disulfide and dimethyl trisulfide, and a few halogenated hydrocarbons. The preliminary results suggest that both biogenic and anthropogenic sources were represented. Also, air-sea gas exchange and other physical processes may be important non-biological sinks.

Published in: *Organic Geochemistry, 1: 93-107, 1978,*

Supported by: *NSF Grant OCE 74-22781 and ONR Contract N00014-74-CC 262;NR 083-004.*

STEROL GEOCHEMISTRY OF SEDIMENTS FROM THE WESTERN NORTH ATLANTIC OCEAN AND ADJACENT COASTAL AREAS

Cynthia L. Lee, John W. Farrington and Robert B. Gagosian

Core sections from coastal bay, continental slope, and continental rise surface sediments of the western North Atlantic were analyzed for sterols. Changing rate or type of sediment input, bioturbation, and chemical conversion appear to be processes important in controlling the distribution of sterols in these sediments. Comparisons of individual sterol distributions and variation in the ratio of Soxhlet-extractable to non-extractable saponified sterols indicate that for the western North Atlantic, the extent to which each process is dominant varies with proximity to shore. Evidence is presented to show that sterols in the deep sea may be at least partially terrigenous in origin and not all biogenically derived in the surface waters. These sterols, and by analogy of other labile organic compounds, may serve as a source of carbon for benthic organism metabolism.

Supported by: *ONR Contract N00014-67-C-0241 and NSF Grants OCE 74-09991 and OCE 75-21278.*

C_1-C_5 HYDROCARBONS FROM CORE GAS POCKETS -- IPOD LEGS 56 AND 57

Jean K. Whelan and Shunji Sato

C_1-C_5 hydrocarbons from Legs 56 and 57 sediment gas pockets were analyzed on shipboard. Results suggest that the C_2-C_5 hydrocarbons accompanied biogenic methane and were generated at low temperatures - less than 50°C - possibly by microorganisms. Neopentane, a rare constituent of petroleum, was the major C_5 component (about 80%) through much of Site 438. The compound appeared in smaller amounts at other sites and seemed to correlate with either fractured or coarse-grained sediments. Scatter in C_4 and C_5 isomer ratios and generally good correlation between C_3, C_4 and C_5 components suggests local sources for these molecules.

Supported by: *NSF Grant OCE 77-26990.*

DISSOLVED GASES IN BLACK SEA SEDIMENTS

John M. Hunt and Jean K. Whelan

About 300 samples of dissolved gases in cores brought to the surface were analyzed from Sites 379, 380/380A and 381. Ethane concentrations ranged from 1 to about 1,000 ppm, butanes from 0.1 to 100 ppm and pentane from 0.1 to 20 ppm. At all three sites, the concentration of the higher hydrocarbons increased irregularly with depth. Major changes in concentrations seemed to correlate with lithology. Higher concentrations of methane diffusing into the more permeable beds resulted in a decrease in the higher hydrocarbons in those beds. The ratio of isopentane to normal pentane is about 0.1 at the surface but increases with depth reaching 10 at a depth of 500 m. Neopentane presumably originating from land-derived terpenes is present in relatively large amounts at Site 381. The δC^{13} pdb values for 10 gas samples from Sites

379, 380 and 381 range from -63 to -72 $^{o}/_{oo}$ indicating a biological source for the methane.

Published in: *Initial Reports of the Deep Sea Drilling Project 42(2), D.A.Ross and Y.P.Neprochnov (eds.) pp.661-665, 1978,*

Supported by: *NSF Grant OCE 73-06575.*

C_1-C_7 HYDROCARBONS IN HOLES 379A, 380/380A, AND 381

Jean K. Whelan and John M. Hunt

Light hydrocarbons in the C_1-C_7 range have been found in three drilling sites in the Black Sea. Light hydrocarbons in the C_4-C_7 range have been found in quantities ranging from 2.1 to 1432 ng/g (ppb). The C_2-C_3 hydrocartons were present in amounts from 0.06 to 239 ng/g (ppb). The deeper sediments from Hole 380A yielded more C_4-C_7/C_0 than the shallower but probably older sediments from Hole 381.

Published in: *Initial Reports of the Deep Sea Drilling Project 42(2), D.A.Ross and Y.P.Neprochnov (eds.) pp.673-677, 1978.*

Supported by: *NSF Grant OCE 73-06575.*

VOLATILE ORGANIC COMPOUNDS IN QUATERNARY SEDIMENTS

John M. Hunt and Jean K. Whelan

The distribution of volatile organic compounds in surface sediments varies widely with the depositional environment. Oxygen and sulfur compounds, alkenes and arenes, are more abundant than alkanes in strongly reducing sediments such as those from around Walvis Bay, West Africa. Among the compounds identified by GC-MS were toluene, benzene, 2-methyl-2-butene, 3,5-dimethylcyclopentene, 2-methylfuran, 3-methylfuran, 2-methylbutanal, 3-methylbutanal, 3-pentanone, 2-methylthiophene, 3-methylthiophene and dimethylsulfide. Some of these compounds have the isoprene carbon skeleton.

In a less reducing environment such as the Arabian Sea-Persian Gulf area, a more diverse alkene assemblage was observed including ethylene, propylene, pentenes, hexenes, cyclohexene, methylpentenes and dimethylcyclopentenes. Also, the sediments contained a few very specific alkane structures. The gem-dimethyl hydrocarbons (neopentane, neohexane and neoheptane) were dominant among the branched hydrocarbons. The high concentration of volatile alkenes and oxygen and sulfur compounds is not observed in deep sea drilling samples at depths greater than about 100 meters.

In Press: *Organic Chemistry.*

Supported by: *NSF Grant OCE 77-269391.*

LIGHT HYDROCARBONS IN SEDIMENTS OF DSDP LEG 44 HOLES

John M. Hunt and Jean K. Whelan

Hydrocarbon yields of samples taken from holes drilled on the Blake Plateau were extremely low compared to other areas such as the Black Sea and the west coast of Africa. At Site 388A the concentration of ethane in the total gas at a depth of 250 m was less than 1 ppm compared to 50 ppm in the Black Sea at the same depth. Yields of C_4-C_7 hydrocarbons at Site 388A were only 1% of yields obtained in holes drilled in similar sediments off the west coast of Africa. At Site 391C the ethane content of the gas at 1000 m was 1 ppm compared to 1000 ppm at an equivalent depth in the Black Sea.

Published in: *Initial Reports of the Deep Sea Drilling Project, 44, W.E.Benson and R.E.Sheridan (eds.), pp.651-652, 1978.*

Supported by: *NSF Grant OCE 73-06575.*

CHARACTERIZATION OF BITUMENS AND COALS

John M. Hunt

Elemental analyses can be used to distinguish many bitumens and coals by plotting the data on an H/C vs. (N + S)/O diagram.

Published in: *AAPG Bulletin 62: 301-303, 1978.*

Supported by: *The Mobil Foundation.*

ORGANIC SEDIMENTS

John M. Hunt

Organic sediments contain more than 50% by weight organic tissues or their derivatives. There are two major groups 1) coals derived from the lignin of land plants and characterized by a high oxygen content and 2) bitumen from the lipids of marine and terrestrial plants and animals and characterized by a low oxygen content. The source materials, the deposition and maturation are described in detail.

Published in: *The Encyclopedia of Sedimentology, edited by Rhodes Fairbridge and Joanne Bourgeois (Academic Press, 1978).*

Supported by: *The Mobil Foundation.*

PROCESSES CONTROLLING THE DISTRIBUTION OF BIOGENIC ORGANIC COMPOUNDS IN SEAWATER

Robert B. Gagosian and Cynthia L. Lee

When discussing factors controlling the distribution of organic compounds in seawater, several types of processes must be considered. These include biological production and consumption, geochemical and biological transport processes and chemically and biochemically controlled transformation reactions.

In situ biological production is the major source for organic compounds in seawater and sediments, while heterotrophic consumption is the major sink. The biota also mediate a large number of transformation reactions of specific organic compounds such as oxidation or reduction, bond formation or breakage, or inorganic-organic binding reactions.

The transport of organic compounds can occur both horizontally and vertically through physical, geochemical or biological processes. Atmospheric transport of land-derived natural compounds to the open ocean can take place in a matter of days. Rivers can discharge large quantities of terrestrially derived organic matter into estuaries either continuously or in pulse-events such as storms. The surface layer of the ocean may serve as an important interface for the exchange of organic matter between the atmosphere and the sea in either the vapor or particulate state. The vertical transport of organic matter in the water column on particulate material such as coccolithophore or diatom tests and in fecal pellets must be considered as a potential source of carbon to the benthos. Advection and diffusion in water masses are important processes in transporting dissolved and small particulate material horizontally as well as vertically in the water column. Bottom currents are capable of moving resuspended sedimentary material both vertically and horizontally across the ocean floor, thus controlling grain size distributions and the distribution of associated organic matter. Organic rich sediments from highly productive areas or anoxic basins can serve as sources for gaseous organic compounds such as methane which diffuse into the upper water column and are transported advectively by water masses. All of these processes can interact with and affect the organic compound distribution in seawater.

Published in: *The Organic Chemistry of Seawater, 1979.*

Supported by: *NSF Grants OCE 77-26180 and OCE 77-26084.*

STEROID KETONES IN [illegible] FROM THE SOUTHWEST AFRICAN SHELF

Robert B. Gagosian and Steven O. Smith

Steroid ketones were isolated from a Recent marine sediment in the upwelling zone off the southwest African shelf. The compounds differed primarily in unsaturation at the C-22 position, methylation at C-4 and alkylation at C-24. A potential role for these compounds in the early transformation of sterols in the geological environment is proposed.

Supported by: *NSF Grants OCE 74-09991, and OCE 77-26084; and ONR Contract N00014-66-00241;NP 083-004.*

THE TRANSPORT AND BUDGET OF STEROLS IN THE WESTERN NORTH ATLANTIC OCEAN

Robert B. Gagosian and Gale E. Nigrelli

A general correlation exists between total free sterols, POC, PON, and chlorophyll a in the upper 300 m of the water column in the western North Atlantic Ocean. High values are found in shelf waters and in the subsurface chlorophyll a maximum in the Sargasso Sea, lower values being observed at a Gulf Stream meander station.

A diatom sterol, 24-methylcholesta-5, 22-dienol, appears to be produced only within the euphotic zone. Below this zone consumption or removal processes dominate and the concentration of this compound decreases with depth. On the other hand, a zooplankton sterol, cholesterol, occurs throughout the entire water column exhibiting maxima at the base of the mixed layer and at depths in the water column where particles tend to accumulate because of favorable chemical or density gradient conditions.

From flux calculations, we find that a maximum of 0.05-0.3% of the sterols produced by phytoplankton in Sargasso Sea surface waters are deposited to the ocean floor. The sterol residence time (the average lifetime of a sterol molecule before it is metabolized) in the euphotic zone was calculated to be approximately one month, whereas the deep water residence time value was found to be 20-150 years.

Supported by: *NSF Grants OCE 74-09991 and OCE 77-26084.*

A VERSATILE INTERCHANGEABLE CHAMBER SEAWATER SAMPLER

Robert B. Gagosian, Jerome P. Dean, Jr., Robert Hamblin and Oliver C. Zafiriou.

A 30 l seawater sampling device which can be lowered closed through the sea-air interface is described. The sampler is designed to allow for interchangeable containers so that aluminum or glass cylinders for organic analyses couid be replaced by P.V.C. or other plastics for trace metal analyses.

Supported by: *NSF Grants OCE 76-09991 and OCE 74-22781.*

STERENES IN SURFACE SEDIMENTS FROM THE SOUTHWEST AFRICAN SHELF AND SLOPE

Robert B. Gagosian and John W. Farrington

Surface sediment samples collected from the southwest African (Nambian) shelf and slope have been analyzed for their hydrocarbon content. In the surface samples a class of olefinic isoprenoid hydrocarbons, the sterenes, have been found to represent 20-40% of the total hydrocarbons. To the best of our knowledge sterenes have not been reported in surface marine sediments in such high contrations.

Cholest-2-ene, cholestadiene cholestatriene, 24-methylcholest-2-ene, 24-methylcholestadiene, 24-ethylcholest-2-ene and 24-ethylcholestadiene were found in the sediments and identified by high resolution glass capillary gas chromatography mass spectrometry.

The formation of the sterenes via microbiological or chemical autooxidation of their oxygenated precursors the sterols followed by subsequent dehydration mechanisms and double bond isomerizations are postulated.

Published in: *Geochimica et Cosmochimica Acta, 42: 1091-1011, 1978.*

Supported by: *ONR Contract N00014-66-C-0241:NR 083-004 and NSF Grant OCE 74-09991.*

MEETING REPORT: FUTURE RESEARCH PROBLEMS IN MARINE ORGANIC CHEMISTRY

Robert B. Gagosian, Saiyed I. Ahmed, John W. Farrington, Richard F. Lee, Richard F.C. Mantoura, Kenneth H. Nealson, Theodore T. Packard and Kenneth L. Reinhart,Jr.

This report describes the results of an IDOE-NSF workshop identifying promising opportunities in chemical oceanographic research for the 1980's. The section dealing with Marine Organic Chemistry and associated biochemical problems attempted to identify the major important areas for future research in Marine Organic Chemistry. The deliberations of this subsection are dealt with in this manuscript.

Published in: *Marine Chemistry, 6: 481-491, 1978.*

Supported by: *NSF Grant OCE 74-22781.*

STEROL COMPOSITION OF CIONA INTESTINALIS

Kishan C. Gupta, Richard L. Miller, John R. Williams, Robert B. Gagosian and Franz Heinzer

The sterol structures and composition of the sponge *Ciona intestinalis* have been determined. Cholesterol (38%) was found to be the major sterol among the eighteen sterols identified. The sterol composition of these lower invertebrates is very complex and is probably due to the diet of these organisms from different localities.

Supported by: *NSF Grant OCE 77-20084.*

STENOLS AND STANOLS IN THE OXIC AND ANOXIC WATERS OF THE BLACK SEA

Robert B. Gagosian and Franz Heinzer

Water samples collected from a slope station and two deep stations in the western basin of the Black Sea were analyzed for stenols and stanols by glass capillary gas chromatography. These results were used in conjunction with hydrographic, particulate organic carbon, and chlorophyll a data to better understand sterol sources and their transport and transformation mechanisms in anoxic basins.

The total free sterol concentrations found in the surface waters were 450-500 ng/l dropping rapidly to values well below 100 ng/l at depths below the O_2/H_2S interface. Structural elucidation by a gas chromatograph-mass spectrometer-computer system revealed the presence of at least sixteen different stenols and stanols in the surface waters of the Black Sea. Cholesterol, 24-methylene-cholesterol and 24-methylcholesta-5,22-dien-38-ol were the major sterols in the surface waters. Cholesterol and 24-ethylcholesterol both exhibited a subsurface maximum at the O_2/H_2S interface. In the anoxic deep waters (200-2000 m) only cholesterol and 24-ethylcholesterol were found. Two stenols were found that have not been reported in seawater: a C_{26} stenol with a saturated C_7H_{15} side chain (presumably 24-norcholesterol) and 24-ketocholesterol. At least six 5α-stanols could be identified in the surface samples, each of them

comprising about 10-20% of the concentration of the corresponding Δ5-stenol. From these comparatively high surface values the stanol concentrations drop rapidly to values near zero at the O_2/H_2S interface. Except for very low concentrations of 5α-cholestanol (<5 ng/l) no other stanols could be detected in the anoxic zone.

From this data it appears that no detectable stenol → stanol conversion is occurring at the O_2H_2S interface or in the deep anoxic waters of the Black Sea.

Supported by: *NSF Grants OCE 74-09991 and OCE 77-26084 and a SWISS National Science Foundation Postdoctoral Fellowship to Franz Heinzer.*

AMINO ACIDS IN INTERSTITIAL WATERS OF MARINE SEDIMENTS

Susan M. Henrichs and John W. Farrington

Interstitial waters of marine sediments from coastal and deep water stations in the northwestern Atlantic Ocean have been analyzed for dissolved free amino acids. Very high concentrations, on the order of 1 mg/l, were found. The amino acid composition of these samples differed substantially from that of seawater and the associated sediment, particularly in the large relative abundances of glutamic acid and β-aminoglutaric acid. β-aminoglutaric acid is an isomer of glutamic acid which, to our knowledge, has not previously been reported in geological materials.

Supported by: *ONR Contract N00014-74-C-0262;NR 083-004 and Paul M. Fye Fellowship to S.M.Henrichs through the WHOI Education Program.*

THE RATES OF TRANSPORT AND FATES OF PETROLEUM HYDROCARBONS IN A CONTROLLED MARINE ECOSYSTEM AND A NOTE ON ANALYTICAL VARIABILITY

Juanita N. Gearing, Patrick J. Gearing, Terry Wade, James G. Quinn, Harry B. McCarty, John W. Farrington and Richard F. Lee

In order to predict the chemical behavior of oil spilled in a marine environment, it is necessary to quantify the rates of the different transport mechanisms operating on the oil. At the Marine Ecosystems Research Laboratory (MERL), University of Rhode Island, the fluxes of water and sediment are controlled, making possible accurate budgeting of petroleum hydrocarbons in an environment approximating a temperate estuary.

Four separate laboratories have cooperated in a study on the MERL tanks to which known amounts of water-accommodated No. 2 fuel oil have been added. A preliminary budget has been completed, indicating that the primary loss was to the atmosphere via evaporation. Biodegradation was important for some class of hydrocarbons and increased with temperature and duration of oil exposure. Particulate material adsorbed hydrocarbons amounting to approximately 10% of the oil added to the tanks, and carried them to the sediment where 3-7% of the added oil was eventually found. The sedimentary hydrocarbons were depleted in low molecular weight aromatic compounds (up to 3 rings) relative to the original oil.

An unexpected but valuable result of these studies has been a better understanding of the levels of variability to be expected when naturally inhomogeneous systems are studied by different methods in different laboratories. Variability has been determined for measuring lipids in uncontaminated water ($\bar{x}$ = 8.2 μg/ℓ, σ_{n-1} = 6.5, one laboratory, 43 samples taken over a period of 8 weeks) and in tank sediments ($\bar{x}$ = 146 μg/g dry weight, σ_{n-1} = 33.6, two laboratories, 37 samples taken over a period of six months). Comparisons have also been conducted on rats of biogradation obtained by two different methods (gas chromatographic analyses of water column hydrocarbons with emphasis on the changing ratios of n-alkanes to isoprenoids, and laboratory studies of individual radiolabelled hydrocarbons converted to $^{14}CO_2$).

Supported by: *EPA Grant (R803902020).*

THE MUSSEL WATCH

Edward D. Goldberg, Vaughan T. Bowen, John W. Farrington, George Harvey, John H. Martin, Patrick L. Parker, Robert W. Risebrough, William Robertson, Eric Schneider and Eric Gamble.

The levels of four sets of pollutants (heavy metals, artificial radionuclides, petroleum components, and halogenated hydrocarbons), have been measured in U.S. coastal waters, using bivalves as sentinel organisms. The strategies of carrying out this program are outlined and the results from the first year's work are given. Varying degress of pollution in U.S. coastal waters have been indicated by elevated levels of pollutants in the bivalves, which comprised certain species of mussels and oysters and were collected at over one hundred localities.

A given pollutant or set of pollutants may have a single source or a multiplicity of sources. For example, the high levels of DDT and its metabolites in mussels living in waters in the San Pedro, California, area result from an input from the Whites Point outfall as a consequence of a manufacturing dis-

charge. The plant switched to a sanitary landfill disposal operation in the early 1970's and the present-day fluxes arise from residual material in the sewer pipe or in the sediments. The high plutonium levels in mussels from Plymouth Bay reflect a unique source from a nuclear fuel facility. On the other hand, inputs from a variety of sources are evident for polychlorinated biphenyls in San Francisco Bay, San Pedro Harbor, and the New York - Boston area coastal zones. The overall effect is noticeable over background levels, presumably arising as a consequence of atmospheric transport. A similar situation exists for the petroleum pollution in Galveston Bay. In none of the localities investigated was pollution evident simultaneously from all four sets of pollutants that were being monitored.

Published in: *Environmental Conservation 5(2). 1978.*

Supported by: *EPA Grant Agreement R84 0215010.*

ANALYSES OF AROMATIC HYDROCARBONS IN INTERTIDAL SEDIMENTS RESULTING FROM TWO SPILLS OF NO.2 FUEL OIL IN BUZZARDS BAY, MASSACHUSETTS

John M. Teal, Kathryn Burns and John W. Farrington

We have analyzed the two and three-ring aromatic hydrocarbons from the Wild Harbor oil spill, September, 1969, and Winsor Cove oil spill in October, 1974 in intertidal marsh sediments, using glass capillary gas chromatographic and mass fragmentographic analyses. Naphthalenes with 0 to 3 alkyl-substitutions and phenanthrenes with 0 to 2 substitutions decreased in concentration in surface sediments. The more substituted aromatics decreased relatively less and in some cases actually increased in absolute concentration. The changes in composition of the aromatic fraction have potential consequences for the ecosystem and provide insight into geochemical processes of oil weathering.

Published in: *Journal Fisheries Res.Bd. Canada, 35: 510-520.*

Supported by: *EPA Grant R802724; NSF Doctoral Dissertation Improvement Grant #40987; a Grant from the Victoria Foundation; and ERDA Contract EE-77-5-02-4256 and Bureau of Land Management via Interagency Agreement AA550-IA-7-20.*

AN OVERVIEW OF THE BIOGEOCHEMISTRY OF FOSSIL FUEL HYDROCARBONS IN THE MARINE ENVIRONMENT

John W. Farrington

Analyses of hydrocarbons in the aquatic environment are reviewed within the context of biogeochemical research. Intercalibration of analyses of hydrocarbons in surface sediments show as much as a factor of 30 discrepancy between data reported by different latoratories. Chronic release of fossil fuel compounds to the marine environment from fossil fuel combustion, sewage sludge, and harbor dredge spoils are discussed. Examples cited and discussed include studies of New York Bight surface sediments and mussels and oysters from the U.S. East and Gulf Coasts using glass capillary gas chromatography-mass spectrometer-computer systems analyses of aromatic hydrocarbons. Recommendations for future studies are presented and range from "bench chemistry" solubility studies to studies of the global transport of hydrocarbons by aeolian and fluvial processes.

Supported by: *U.S.Department of Energy Contract No.EE-77-5-02-4256; The U.S.Bureau of Land Management Interagency Agreement AA-550-IA-7-20 and U.S.Environmental Protection Agency, Grant 804215, R803902020.*

THE NATURE OF GROWTH FORMS IN THE SALT MARSH GRASS SPARTINA ALTERNIFLORA

Ivan Valiela, John M. Teal and Werner G. Deuser

Spartina alterniflora Loisel., the salt marsh cordgrass, is the dominant plant of salt marshes on the Atlantic coast of North America, and may be found in two markedly different growth forms. The tall form has thick stems and may reach 2-3 m in height, has few plants per unit area, and grows on banks of tidal creeks. The dwarf form is about 10-40 cm high, grows quite densely, and is commonly found on flat marsh sediments landward of the tall form.

Taxonomic studies reviewed by Shea *et al.* (1975) and Chapman (1960) speak of distinct tall and dwarf ecotypes. Transplantation experiments led Stalter and Batson (1969) to conclude that *S. alterniflora* had "inherently" dwarf and tall forms. On the other hand, Mooring *et al.* (1971) grew similar seedlings in the laboratory from seed harvested from dwarf, intermediate, and tall plants. Shea *et al.* (1975) carried out transplantation and electrophoretic studies showing that there was no apparent genetic component to the differences between the growth forms.

We have been conducting long-term fertilization experiments on plots in Great Sippewisset Marsh, Massachusetts. One unexpected

result of these enrichment experiments was a shift in plant morphology from a short sward of *S. alterniflora* to vegetation resembling the tall form in leaf width, stem diameter and general appearance (Valiela *et al.* 1975). This paper considers the results from the enrichment studies, evaluates the effects of nutrients on properties of short and tall *S. alterniflora*, and attempts to explain the occurrence of the growth forms in the field.

Published in: *The American Naturalist, 112: 461-470 (1978).*

Supported by: *Victoria Foundation, and NSF Grants OCE 28365 and OCE 28272.*

GEOCHEMISTRY

AN EVALUATION OF THE BEHAVIOR OF THE RARE EARTH ELEMENTS DURING THE WEATHERING OF SEA-FLOOR BASALT

John N. Ludden and Geoffrey Thompson

We present rare-earth element (REE) data for fresh and altered tholeiitic basalts sampled during a dredging transect at 23°N in the Atlantic Ocean and covering a time span of 0 to 57 million years. These data have been used to evaluate the behavior of the REE during low-temperature weathering processes. Compositional trends from altered basalt interiors to palagonitized rinds in individual pillow samples indicate significant mobility of the light-REE: some elements are enriched by four orders of magnitude in rinds relative to interiors. The heavy-REE show no selective mobilization and can be used in a normalization procedure which indicates that the light-REE are enriched in altered interiors relative to fresh interiors of the basalts. Cerium behaves anomalously and accords with either its abundance in seawater or its fractionation from seawater during the formation of ferromanganese deposits.

These results indicate that REE data from fresh glassy or crystalline basalt samples only may be used with confidence in petrological models.

Supported by: *NSF Grant OCE 74-22971 and an OIP Grant of W.H.O.I.*

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

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_2 > 2.0 wt.%). Their trace element abundances indicate a tholelitic 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 chondrite-normalized REE patterns.

Quantitative models, involving major and trace element abundances and phase compositions, demonstrate: (1) In terms of most major elements and phase composition Site 214 and 216, ferrobasalts can be related by fractionation involving clinopyroxene and plagioclase from the more basic Site 214 liquids. However, the contents of Ti, K, Zr and light-REE in Site 216 basalts are greater than implied by the fractional crystallization model. This excess may reflect primary characteristics arising during the partial melting process. (2) The basalts from Site 214 can be related to the overlying oceanic andesites by a fractionation model involving removal of clinopyroxene and plagioclase, and subsequent fraction of magnetite. (3) Site 254 basalts, at the southern end of the ridge, and the Amsterdam - St.Paul volcanic province are inferred to represent the most recent activity associated with the hot-spot forming the 90°E Ridge. A liquid parental to the ferrobasalts of Sites 214 and 216 is considered to have a composition intermediate to that of incompatible element depleted mid-ocean ridge tholeiites and incompatible element enriched island tholeiites similar to those of Site 254 and the Amsterdam - St.Paul volcanic province.

Supported by: *NSF Grants OCE 74-00147 and OCE 74-00268. Also WHOI OIP Grant.*

OPTICAL EMISSION SPECTROMETER/SPECTROGRAPH FOR MAJOR AND MINOR OXIDE AND TRACE ELEMENT ANALYSIS OF SILICATE ROCKS

Donald C. Bankston, Susan E. Humphris and Geoffrey Thompson

A technique for the determination of major concentrations of SiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O, and K_2O, minor levels of TiO_2, P_2O_5 and MnO, and trace concentrations of Ba Cr, Cu, Ni, Sr, V, and Zn, in semi-microsamples (200 mg) of powdered whole rock, is described. Chemically diverse standard reference rocks are used both for calibration and assessment of accuracy. A lithium metaborate fusion melt of each standard or sample is dissolved in dilute HNO_3 containing Cs^+ concentration has been raised to 0.2% (w/v). The resulting solution is used to perform all analyses except those for Na_2O and K_2O, which are determined in a portion of the original sample solution wherein the Cs^+ concentration has been raised to 0.32% (w/v). Analyses of

both portions of each sample solution are performed using an optical emission spectrometer/spectrograph equipped with an echelle monochromator and a dc argon plasma excitation source. Trace element detection limits ranted from 2 ppm for Cu, to 15 ppm for Zn. A study of precision based on replicate determination in three splits of the proposed U.S.G.S. reference basalt BHVO-1 yielded the following results: (1) For analysis of the major and minor oxide constituents, values of the percent relative standard deviation (RSD) ranged from 0.99 for CaO, to 21.31 for P_2O_5. (2) For trace element determinations, values of the RSD ranged from 1.85 for Cu, to 18.88 for Zn.

Supported by: *NSF Grant OCE 75-22971.*

TRACE ELEMENT ANALYSES OF ALLENDE METEORITE REFERENCE SAMPLE

Geoffrey Thompson

A meteorite reference sample has been prepared for analysis of meteorites, lunar samples, and other geologic materials. Four kilograms of the Allende meteorite were powdered and split into one or five gram subsamples. Two sub-samples each were made available to several laboratories for analysis. Chemical data was obtained for fifty elements by means of different analytical techniques. The data was evaluated for homogeneity and precision. For twenty-nine elements, "recommended values" are suggested.

Supported by: *NSF Grant OCE 74-22971.*

GEOLOGICAL AND GEOPHYSICAL INVESTIGATION OF THE MID-CAYMAN RISE SPREADING CENTER: INITIAL RESULTS AND OBSERVATIONS

Robert D. Ballard, Wilfred B. Bryan, Karleen Davis, Jelle deBoer, Steve DeLong, Henry J.B.Dick, Kenneth O. Emery, Paul J. Fox, Mark Hempton, Freida Malcolm, William G. Melson, Randall Spydell, Janet Stroup, Geoffrey Thompson, Raymond Wright and Elazar Uchupi

This paper represents a general summary of a multi-institutional field program that spanned two field seasons, and that involved traditional surface ship marine geophysical and geological techniques, a deep-toned camera system (ANGUS), a submersible (DSRV *ALVIN*), a bathyscaph (DSRV *TRIESTE II*), and the United States Navy multi-narrow beam sonar mapping system (SEABEAM). These diverse, intensive and sophisticated tools provided investigators with a plethora of data that is still undergoing analysis. This presentation is not meant to be conplete synthesis of our program, but rather an attempt to identify the types of data that we recovered, to summarize the results of our work to date, and to identify the aims of our ongoing investigations. This general and integrated presentation is not meant to supplant the specific and in-depth papers, authored by a subset of the authors of this paper, that will follow during the coming year.

Supported by: *NSF Grant OCE 75-18533.*

THE BEHAVIOR OF THE RARE EARTH ELEMENTS DURING SUBMARINE WEATHERING OF THOLEIITIC BASALT

John N. Ludden and Geoffrey Thompson

Rare earth element analyses of pillow basalts ranging from 0 to 5 million years are presented. The data indicate significant uptake of the light rare earth element La-Sm during sea floor basalt weathering basalt processes at low temperatures. This process is accelerated in the palagonitized kinds of the pillows, all of which are completely altered by four million years. Although the weatehring effect is slower in the crystalline interiors of the pillow basalts, we observe the same process of light REE enrichment.

Supported by: *NSF Grant OCE 74-22971 and the OIP of W.H.O.I.*

VERY LOW TEMPERATURE HYDROTHERMAL ALTERATION OF THE OCEANIC CRUST AND THE PROBLEM OF FLUXES OF POTASSIUM AND MAGNESIUM

Thomas W. Donnelly, Geoffrey Thompson, and Paul T. Robinson

A chemical study of 200 meters of highly altered basalt from Hole 417A shows that potassium is strikingly enriched in these rocks, and that calcium, magnesium, and sodium are all depleted. Manganese is very slightly depleted and phosphorous slightly enriched. A comparison of these rocks with fresher examples from nearby Hole 417D suggests that they were originally the same materials. Silicon, titanium, total iron, and aluminum cannot be shown to have moved during alteration.

A calculation of the budget of alteration shows that about 690 grams of potassium has been introduced for a 200 meter column of rock 1 cm^2 in cross section. Because hydrogen ion is needed to maintain electrical balance, bicarbonate is probably consumed, yielding carbonate ion. If seawater is the altering fluid, then differing assumptions as to the original porosity show that 700 to 1600 volumes of the original voids must have been supplied, if potassium is the limiting chemical species and if it is completely removed from the water. Assuming a low temperature of alteration (on the basis of mineralogy and oxygen isotopes)

the amount of heat necessary to drive the required volume of water through the rock must come from a crustal section in excess of what was drilled.

Oxygen isotopic data agree with mineralogical observations that the alteration occurred at low temperatures, but in the presence of warm water. We have coined the term "mesothermal" to describe such alteration processes, which apparently result from the effect of upward moving-water removing heat from a cooling crust.

Mesothermal alteration causes the crust to lose some magnesium and take up large amounts of potassium, an effect the reverse of higher temperature hydrothermal alteration. Because the sizes of the elemental fluxes are very large, an understanding of the total chemical interaction between the oceanic crust and sea water requires a thorough knowledge of the relative importance of alteration at the two temperature ranges.

Supported by: *NSF Grant OCE 74-22971.*

THE CHEMISTRY OF ALTERED BASALTS AT SITE 417A, DSDP LEG 51

Thomas W. Donnelly, Geoffrey Thompson and Matthew Salisbury

A chemical study of 200 meters of highly altered basalt from Hole 417A shows that potassium is strikingly enriched in these rocks, and that calcium, magnesium, and sodium are all depleted. Manganese is very slightly depleted and phosphorous slightly enriched. A comparison of these rocks with fresher examples from nearby Hole 417D suggests that they were originally the same materials. Silicon, titanium, total iron, and aluminum cannot be shown to have moved during alteration; a small difference in estimated original aluminum composition is explained on the basis of original variation in plagioclase content. Of the minor elements, lithium, boron, and barium are strongly enriched, and none of the elements can be shown to be generally depleted, although several (yttrium, strontium, nickel) are slightly redistributed during alteration.

A calculation of the budget of alteration shows that about 690 grams of potassium has been introduced for a 200 meter column of rock 1 cm^2 in cross section. Because hydrogen ion is needed to maintain electrical balance, bicarbonate is probably consumed, yielding carbonate ion. Oxygen is generated by the alteration process in excess of that needed to oxidize the ferrous iron, although probably in the form of water. If seawater is the altering fluid, then differing assumptions as to the original porosity show that 700 to 1600 volumes of the original voids must have been supplied, if potassium is the limiting chemical species and if it is completely removed from the water.

Assuming a low temperature of alteration (on the basis of mineralogy and oxygen isotopes) the amount of heat necessary to drive the required volume of water through the rock must come from a crustal section in excess of what was drilled.

Published in: *DSDP Initial Reports, 51.*

Supported by: *NSF Grant OCE 74-22971.*

PETROLOGIC CHARACTER OF THE ATLANTIC CRUST FROM DSDP AND IPOD DRILL SITES

Wilfred B. Bryan, Geoffrey Thompson and Frederick A. Frey

Basement rocks recovered by DSDP and IPOD drilling in the Atlantic are predominantly pillowed or massive basalt lava flows which resemble modern Mid-Atlantic Ridge (MAR) basalts in their range of chemical composition and petrographic characteristics. Basalts from the oldest sites drilled (70-150 m.y.) generally resemble modern basalts presently being erupted at the locations on the MAR where these older basalts should have originated; all of these represent "normal" ridge segments unaffected by "mantle plume" activity. The Leg 37 transect drilled opposite the Azores "mantle plume" or "blob" shows evidence of some fluctuation in geochemical parameters, possibly indicating short-term fluctuations in plume activity.

Only two sites (334 and 395) have penetrated layer 3 plutonic rocks, but it is likely that these are tectonically emplaced, and the true thickness of layer 2 has not been defined by drilling. In general the transition from sediment to basalt basement is sharp. Excellent core recovery at Sites 417 and 418 shows that pillowed and massive flows are interbedded; dikes and sills are rare at these and other sites but probably are hard to recognize unless core recovery is very good. Drilling at Site 417 suggests that intense low temperature alteration may be limited to topographic highs which are not immediately buried by sediment. Hydrothermal alteration and metamorphism are not encountered in the sites so far drilled.

Most DSDP and IPOD sites have not been well-placed to indicate the persistence of "mantle plumes" with time, although north-south geochemical variations in continental Triassic basalts resemble those documented for modern basalts associated with the Azores plume and suggest that such plumes may have initiated spreading in the Atlantic. Future drilling should be designed to define the persistence of such plumes in time and space, and also should attempt to penetrate the

lower part of layer 2 and the upper part of layer 3 in a crustal section of normal thickness.

Supported by: *NSF Grant OCE 76-15858.*

DC PLASMA EMISSION SPECTROMETRY FOR ELEMENT DETERMINATIONS IN IGNEOUS ROCKS

Donald C. Bankston, Susan E. Humphris and Geoffrey Thompson

The development and routing application are described of a technique for the rapid determination of major concentrations (as oxides) of Si, Al, Fe, Mg, Ca, Na, and K, minor levels (also as oxides) of Ti, P, and Mn, and trace concentrations of Ba, Cr, Cu, Ni, Sr, V, and Zn, in 200 mg samples of powdered whole rock. A lithium metaborate fusion melt of each sample is dissolved in (1 + 24) HNO_3 containing CsCl at a concentration of 0.2534% (w/v). From this solution a portion is taken, and the concentration of CsCl in it is raised to 0.4% (w/v). This high-cesium sample solution is used for the analyses of Na and K, while the remaining elements are determined in the original low-cesium solution. The only analytical instrument employed is an emission spectrometer/spectrograph equipped with an echelle monochromator and a dc plasma jet excitation source. In the determination of each element, one chemically and mineralogically diverse set of standard reference rocks is used for calibration, while another group is employed to assess accuracy. Reproducibly high levels of cesium and lithium present in all of the solutions used in each analysis uniformly minimize any matrix effects resulting from ionization interferences.

Supported by: *NSF Grant OCE 74-22971,*

THE NATURE AND PETROGENESIS OF INTRA-OCEANIC PLATE ALKALINE ERUPTIVE AND PLUTONIC ROCKS: KING'S TROUGH, NORTHEAST ATLANTIC

Jonathan Stebbins and Geoffrey Thompson

Basalts, diorites, and gabbros dredged from the side of King's Trough - a mid-plate fracture on the northeast Atlantic sea floor - are alkaline in character based on major and trace element chemistry and mineralogy. The variation in bulk chemical composition and in mineral paragenesis and composition suggest differentiation in a large magma chamber beneath a seamount volcano. Fractional crystallization took place in a hydrous magma and is characterized by early formation of a Ti-rich biotite as rims on olivine. Thus, pyroxene compositions are unusual in having relatively low molar Ti/Al ratios, and increasing differentiation is marked by progressively decreasing ratios of K to Na.

Published in: *Journal Volcanology and Geothermal Research, 1978.*

Supported by: *NSF Grant OCE 74-22971.*

CHEMICAL VARIATION IN GLASS-WHOLE ROCK PAIRS FROM INDIVIDUAL COOLING UNITS IN HOLES 417D AND 418A

H. Staudigel, Wilfred B. Bryan and Geoffrey Thompson

Graphical constructions, least sequence calculations, and petrographic observations combined with detailed major and trace element analyses indicate that secular crystal accumulation has played an important role in modifying initial liquid compositions of basalts in IPOD Sites 417D and 418A. We conclude from whole rock trace element and major element data, and from microprobe plan analyses that these basalts were formed from a very homogeneous melt (by high degree of partial melting) and which was subsequently modified by two magnetic processes: shallow level crystal fractionation which yielded the variation in liquid composition, and by phenocryst redistribution by crystal settling on floating and/or dynamic sorting in lava tubes which yielded the variation in whole rock compositions.

Supported by: *NSF Grant OCE 76-15858.*

THOLEIITIC AND ALKALI BASALTS FROM THE MID-ATLANTIC RIDGE AT 43°N

Twugio Shibata, Geoffrey Thompson and Frederick A. Frey

Tholeiitic basalts dredged from the Mid-Atlantic Ridge (MAR) axis at 43°N are enriched in incompatible trace elements compared to the "normal" incompatible element depleted tholeiites found from 49°N to 59°N and south of 33°N on the MAR. The most primitive 43°N glasses have MgO/Fe* = ~1.2 and coexist in equilibrium with olivine (Fo_{90-91}) and chrome-rich spinel. This primitive magma type is distinct from the strongly incompatible trace element depleted tholeiites found elsewhere in the Atlantic (e.g., 28°S, Frey *et al.*, 1974), and it has trace element features typical of island tholeiites and MAR axis tholeiites from 45°N. Petrographic, major and compatible trace element trends of the axial valley tholeiites at 43°N are consistent with shallow level fractionation; in particular, evolution from primitive liquids with forsteritic olivine plus chrome spinel as liquidus phases to fractionated liquids with plagioclase plus clinopyroxene as major crystallizing phases. However, each dredge haul has distinctive incompatible element abundances. These trace element characteristics require a heterogeneous mantle or complex processes

such as open system fractional crystallation and magma mixing.

Alkalic basalts (~5% normative nepheline) were dredged from a prominent fracture zone at 43°N. Typical of alkalic basalts they are strongly enriched (compared to tholeiites) in incompatible elements. Their highly fractionated rare-earth element (REE) abundances require residual garnet during partial melting. The 43°N tholeiites and alkalic basalts could be derived from a garnet peridotite source with REE contents equal to 2x chondrites by ~7% and 1% melting, respectively. Alternatively, they could be derived from a moderately light REE enriched source by ~25% and ~7% melting, respectively.

Supported by: *NSF Grants OCE 76-22971 and OCE 77-26842.*

CATION EXCHANGE CHARACTERISTICS OF AMAZON RIVER SEDIMENT AND ITS REACTION WITH SEAWATER

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

The cation-exchange characteristics of Amazon River suspended sediment and its reaction with seawater have been studied in order to determine the contribution of exchangeable cations to the geochemical fluxes from the river. Sediment samples were obtained throughout most of the Amazon Basin. The range of exchangeable cation compositions is very narrow in the river and in seawater as well. In river water, the exchangeable cation complement (equivalent basis, exclusive of H^+) is 80% Ca^{2+}, 17% Mg^{2+}, 3% Na^+ plus K^+. In seawater Na^+ and Mg^{2+} are about equal (38%) while Ca^{2+} ~ 15% and K^+ ~ 9%.

On reaction with seawater, river suspended sediment took up an amount of Na^+ equal to nearly one-third of the dissolved river load, as well as amounts corresponding to 15-20% of the dissolved fluvial K^+ and Mg^{2+}. These estimates reflect an unusually high suspended sediment:dissolved-solids ratio of 6.4 at the time of sampling. At a more representative world average ratio of 4, the uptake of Na^+ would be 20% of the dissolved fluvial load, and that for K^+ and Mg^{2+} about 10%. Over the annual cycle of the Amazon, it is estimated that cation-exchange has a still smaller effect, as a consequence of the low average suspended-solids:dissolved-solids ratio of 1.7.

Variations in the ratio X_{Ca}/X_{Mg}, the equivalent fraction of exchangeable Ca^{2+} and Mg^{2+}, throughout the river, can be described by a single isotherm. This same isotherm accurately describes the distribution of exchangeable Ca^{2+} and Mg^{2+} on sediment equilibrated with seawater, despite the fact that a high proportion of exchange sites are occupied by Na^+ and K^+.

Supported by: *NSF Grant OCE-10277.*

THE COMPOSITION AND DIAGENESIS OF INTERSTITIAL SOLUTIONS: 1. FLUXES ACROSS THE SEAWATER-SEDIMENT INTERFACE IN THE ATLANTIC OCEAN

Frederick L. Sayles

Studies of the composition of interstitial solutions of marine sediment have been carried out utilizing *in situ* sampling techniques. Samples were obtained from the Caribbean, North Atlantic and South Atlantic. In virtually all cases, diagenesis has led to the uptake of Mg^{2+} and K^+ and the release of Ca^{2+}, HCO_3^- and Na^+ by the solid phases. SO_4^{2-} is slightly enriched at nearly all stations. Cl^- is conservative within experimental precision.

The reactions controlling the fluxes of most components across the water-sediment interface occur almost entirely in the upper 100 cm of sediment. Contributions of Mg^{2+}, Ca^{2+}, K^+ and HCO_3^- from below 100 cm amount to less than 15% of the calculated fluxes across the interface. Reactions in the upper 30 cm account for 70-90% of the fluxes of these components across the interface. Only Na^+ has a deep source, gradients often being linear in the upper two meters of sediment.

Calculated fluxes across the sediment-water interface are of the same order of magnitude as river inputs for the components studied. In the case of Mg^{2+} and K^+, 35-80% of the river input can be balanced by diagenetic uptake in the sediment. For Ca^{2+} and HCO_3^- additions to seawater augment the river supply by 20-30%. When the uptake of Mg^{2+} nd K^+ by the sediment is calculated by integrating the fluxes across the interface, calculated concentrations of both of these elements are inconsistent with published average concentrations for the types of sediment studied.

Supported by: *NSF Grant OCE 76-81620.*

CHEMISTRY AND MINERALOGY OF SPILITES FROM THE OCEAN FLOOR: EFFECT OF SEAWATER/BASALT RATIO

William E. Seyfried,Jr., Michael J. Mottl and James L. Bischoff

Chemistry exchange and secondary mineral formation during experimental alteration of basalt by seawater is greatly affected by seawater/rock ratio. Such an effect, brought about by variations in permeability within the oceanic crust at spreading centers, can account for the chemical and mineralogic diversity commonly observed in oceanic spilites.

Published in: *Nature 275: 211-213, 1978.*

Supported by: *NSF Grant IDO 74-12880.*

CHEMICAL EXCHANGE DURING HYDROTHERMAL ALTERATION OF BASALT BY SEAWATER - I. EXPERIMENTAL RESULTS FOR MAJOR AND MINOR COMPONENTS OF SEAWATER

Michael J. Mottl and Heinrich D. Holland

Fresh mid-ocean ridge basalt of varying crystallinity has been powdered and reacted with seawater and an artificial Na-K-Ca-Cl solution at 200-500°C and 500-1000 bar in sealed gold capsules. Water/rock mass ratios of 1-3 were used and durations ranged from 2 to 20 months.

These time periods were sufficient for most elements to approach a steady-state concentration in solution which was determined by equilibrium with alteration minerals (Mg, SiO_2, SO_4), by rate of formation of these minerals (Na, Ca), or by depletion from the rock (K, B, Ba). The resulting solutions closely resemble the brines from the basalt-seawater geothermal system at Reykjanes, Iceland. Mg was almost completely removed from seawater into the alteration products smectite, tremolite-actinolite, or talc. Sulfate also was removed to low concentrations, both by precipitation of anhydrite and by reduction to sulfide. Net transfer of Na from seawater into solids occurred in most experiments by formation of sodic feldspar and possibly analcime. Sr was removed from seawater in some experiments, but showed no change or a small gain in others. SiO_2, Ca, K, Ba, B and CO_2 were leached from basalt and enriched in solution. SiO_2 concentrations were controlled by saturation with quartz at 300°C and above. The principal Ca-bearing phases which formed were anhydrite, the hydrated Ca-silicate truscottite, tremolite-actinolite, and possibly wairakite. No K-rich phases formed. For some minerals, the drystallinity of the starting basalt affected the amount which formed.

Removal of Mg from seawater into solid alteration products occurred rapidly and was balanced largely by leaching of Ca from basalt. Net transfer of Na from seawater into solids occurred more slowly and was balanced mainly by leaching of additional Ca from basalt. Thus, reaction between seawater and basalt at low water/rock ratios can be considered to consist of two exchanges: Mg for Ca, and Na for Ca.

Published in: *Geochimica et Cosmochimica Acta* 42: *1103-1115.*

Supported by: *A Harvard University Grant.*

CHEMICAL EXCHANGE DURING HYDROTHERMAL ALTERATION OF BASALT BY SEAWATER - II. EXPERIMENTAL RESULTS FOR Fe, Mn, AND SULFUR SPECIES

Michael J. Mottl, Heinrich D. Holland and Rosamund F. Carr

Fresh mid-ocean ridge basalts of varying crystallinity and an andesite were reacted with seawater and with a Na-K-Ca-Cl solution at 200°-500°C and 500-1000 bars in sealed gold capsules. Water/rock mass ratios of one to three were used and durations ranged from two to twenty months. The concentrations of Fe and Mn, and reduced and oxidized sulfur species in solution, reached a steady state in most of the experiments at 400-500°C but not in those at 200-300°. The concentrations of Fe and Mn were a few ppm at 200-300° and increased greatly with temperature between 300 and 500°. The low values at 200-300° are probably related to the uptake of Fe and Mn by smectite at the *in situ* pH, which was slightly acid at 200° and slightly alkaline at 300°. The quench pH values decreased with increasing temperature above 300°. The only reliable data for the concentration of Zn in solution were obtained at 400°, where values of 1-2 ppm were found. Copper was extensively leached from basalt and andesite, and was deposited as part of a Cu-Au alloy in the capsule walls or, in some experiments, as chalcopyrite.

Reduced sulfur was readily leached from basalt into solution, and was also produced by the reduction of seawater sulfate by ferrous iron derived from the basalts. The proportion of seawater sulfate which was reduced in the experiments with a water/rock ratio of one varied from 5-10% at 300°C to < 95° at 500°. The rate of sulfate reduction depended on the run temperature, on the crystallinity and initial sulfur content of the rocks used as starting materials, and on the water/rock ratio. The final concentration of reduced sulfur in solution increased greatly with temperature, and generally exceeded that of Fe on molal basis.

The oxide-sulfide assemblages produced in the experiments resemble those in the basalt-seawater geothermal system at Reykjanes, Iceland, and in hydrothermally altered basalts and gabbros from the oceanic crust; they include pyrite, pyrrhotite, chalcopyrite, hematite, and probably magnetite. The particular assemblage varied systematically with the temperature, rock type, and crystallinity of each run. Anhydrite precipitated in all experiments with seawater, at all temperatures from 200-500°C. However, its persistence to the end of the runs was apparently metastable, as it should have reacted with

the final solutions to produce pyrote or pyrrhotite.

Supported by: *Grants to Stanford and Harvard Universities and by the Woods Hole Oceanographic Institution.*

SUB-SEA-FLOOR HYDROTHERMAL SYSTEMS: ROCK- VS. SEAWATER-DOMINATED

Michael J. Mottl and William E. Seyfried

Experiments reacting seawater with basalt under hydrothermal conditions have shown that the water/rock ratio effective during alteration has a drastic effect on both the chemistry of the solution and the mineralogy of the solids produced. For the range of water/rock ratios likely to be encountered in sub-seafloor hydrothermal systems, two types of systems can occur: rock-and seawater-dominated. The distinction between the two results largely from the critical role of seawater Mg in generating and maintaining acidity. During reaction with basalt, H^+ is produced by the uptake of seawater Mg and OH^- in the form of a $Mg(OH)_2$-component in smectite or chlorite. As long as high concentrations of Mg and SiO_2 are maintained in solution, the rate of H^+ production exceeds that of H^+ consumption by silicate hydrolysis reactions and the pH stays acid. As a result, concentrations of the heavy metals Fe, Mn, and Zn are high. These conditions are maintained indefinitely in seawater-dominated systems, and the only minerals which form in equilibrium with the solution are smectite, mixed-layer clay, or chlorite, and quartz, hematite, and anhydrite. In rock-dominated systems, by contrast, seawater Mg is almost completely removed into solids and silicate hydrolysis reactions eventually consume the earlier formed H^+, producing a neutral to slightly alkaline solution with low metal concentrations and pH controlled by equilibrium with a complex assemblage of secondary silicates. In the experiments the transition from rock- to seawater-dominated conditions occurred abruptly with increasing water/rock mass ratio at a value of 50 ± 5, the ratio at which the solids became 'saturated' with Mg and depleted in the leachable cations Ca, Na, K, Mn, and Zn.

Whether rock- or seawater-dominated conditions prevail locally within a hydrothermal system depends on the relative rates of fluid flow vs. reaction in that locality, which in turn depend on factors such as permeability surface area, temperature, and type of rock being altered. Seawater-dominated systems are those with water/rock ratios > 50 and possibly smaller, which produce acid, Mg- and metal-rich hot springs. Rock-dominated systems produce hot spring solutions which, prior to mixing with cold seawater, are heavily depleted in Mg and poor in heavy metals.

Supported by: *NSF Grants ID 74-12880 and OCE 77-26842.*

SEAWATER CHEMISTRY

NITRITE PHOTOLYSIS IN SEAWATER BY SUNLIGHT

Oliver C. Zafiriou and Mary B. True

Nitrite is chemically stable but photochemically unstable in seawater. The net disappearance rate in abiotic low-nitrate seawater exposed to sunlight is ∿10% per day. The primary products are the free radicals NO and OH. Quantitative aspects of the kinetics and secondary product formation are discussed in terms of a fourteen-step reaction scheme. Possible pathways explaining the results are suggested but not unequivocally identified.

The rate of reaction in various marine environments is estimated from cruise data and extrapolations to vary between 0.2-60 mM/M^2/yr, with a suggested global average for comparison purposes of 1-10 mM/m^2/yr.

These results confirm and quantify our previous suggestion that nitrite photolysis represents a source of OH radical in seawater. The reaction rate is large enough that significant impacts on the geochemical cycles of dissolved organic carbon and nitrogen and heavy metals may plausibly result. Effects on marine biota and atmospheric trace gas composition are also possible. However, specific reactions coupling the nitrite system to other processes have not yet been identified or demonstrated empirically.

Supported by: *NSF Grants OCE 74-01553 and OCE 77-08696.*

NITRITE PHOTOLYSIS AS A SOURCE OF FREE RADICALS IN PRODUCTIVE SURFACE WATERS

Oliver C. Zafiriou and Mary B. True

Sunlight photolyzes nitrite in natural waters, producing free radicals by

$$NO_2^- + HOH + h\nu \rightarrow NO + OH + OH^-.$$

The primary and secondary radicals may react irreversibly with the medium, or regenerate nitrite as proposed for pure water. We measured net nitrite loss to estimate the irreversible component. Compositionally varied nitrite-rich surface seawaters from the Peruvian coastal upwelling were sealed in glass bulbs, sterilized, and exposed to ambient sunlight or held in darkness. Samples showed light-dependent nitrite losses of 5-27% per day providing the first field evidence for

generation of inorganic free radicals in seawater and their further interaction with the chemical milieu (∿ 90 nmole/ℓ/day). The rate in filtered samples correlated positively with initial chlorophyll a content and negatively with nitrite concentration, indicating that biogenic scavengers and nitrite may compete in a product-determining secondary step. Although nitrate is photolyzable and was present, it did not show photochemical loss.

Supported by: *NSF Grant OCE 77-08696.*

NITRATE PHOTOLYSIS IN SEAWATER BY SUNLIGHT

Oliver C. Zafiriou and Mary B. True

The photolysis of nitrate in seawater has been re-examined using sunlight, abiotic seawater, and naturally occurring concentrations. No significant nitrate concentration decreases could be detected, suggesting an upper limit for the net first-order nitrate loss rage coefficient of 0.2 yr^{-1}. However, photochemical nitrite formation was observed from nitrate. First-order nitrate photolysis rate coefficients calculated from nitrite appearance (corrected for concomitant nitrite photolysis) ranges from 0-2.3 yr^{-1}, median 0.7 yr^{-1}. The coefficients did not correlate well with water chemistry, but decreased with increasing light dose. A first-order rate coefficient 0.4 yr^{-1} was calculated for the primary process $NO_3^- + h\nu = NO_2^- + O(^3p)$ under sea surface equatorial insolation and cloudiness conditions.

The results show some internal inconsistencies and the rates are markedly different from those calculated using data from other studies. Nitrate photolysis rates are concentration- and light dose-dependent. Whether these dependencies explain the apparent discrepancies is unclear, as methodological differences may also be involved. The system requires further study if rates are to be estimated with confidence.

If our median rate estimate applies to surface oceanic conditions, nitrate photolysis proceeds at roughly 0.01-1% of the rate of N incorporation during primary production. Since such reactive species as oxygen atoms, nitrogen dioxide, and hydroxyl radicals are produced, the reaction may have significant consequences in seawater.

Supported by: *NSF Grants OCE 74-01553 and OCE 77-08696.*

EXPLORATORY ANALYSES OF TRICHLOROFLUOROMETHANE (F-11) IN NORTH ATLANTIC WATER COLUMNS

Paul M. Hammer, James M. Hayes, William J. Jenkins and Robert B. Gagosian

Seawater samples collected at four stations in the Gulf of Maine, three on the Scotian Shelf, and at a single station in the Sargasso Sea (Sept.-Oct.,1977) were analyzed for CCl_3F-content using a rapid gas chromatographic technique carried out on board ship. The concentrations observed in the Gulf averaged 2.9×10^{-12} moles/liter, corresponding to significant supersaturation with regard to the overlying atmospheric concentrations and surface temperatures. Not all the excess can be attributed to prior equilibration at the colder temperatures prevailing at higher latitudes, and it seems likely that waste disposal activities may contribute to the local excess. Lower concentrations are observed at stations on the Scotian Shelf and in the Sargasso Sea, with observed stratifications in the CCl_3F concentrations being well-correlated with previously descriged oceanographic features.

It has been suggested (Lovelock *et al.*, 1973; Ostlund *et al.*, 1977) that trichlorofluoromethane ("Freon-11", F-11) might be useful as a transient tracer in oceanographic studies. This compound, which now has an easily detectable atmospheric concentration and a reasonably well-characterized distribution (Rasmussen *et al.*, 1976; Singh *et al.*, 1978), is entirely anthropogenic and has a well-known history of release (McCarthy *et al.*, 1977). It can be expected to dissolve in surface waters to a significant degree (Liss and Slater, 1974; Junge, 1976), and should persist due to its high stability in aqueous solutions (Sanders, 1965; Johnson *et al.*,1973). Because the growth of the atmospheric concentration has been recent and rapid (doubling time ∿ 4 years during 1955-1975), trichlorofluoromethane analyses should be useful in clearly identifying water masses which have had no recent contact with the atmosphere and in indicating the mixing or exposure history of water masses in which CCl_3F is found.

Information about the actual distribution of CCl_3F in seawater, is rare at present, and it has been noted (Östlund *et al.*,1977) that the analyses can be expected to be difficult because most research vessels present severe contamination hazards. For these reasons we have undertaken a series of exploratory measurements in oceanic waters ranging from the surface to Antatctic Bottom Water. A variety of sampling precedures has been used, and at the same time, samples have been collected for correlative ^3He and tritium analyses.

Published in: *Geophysical Research Letters, 5(8): 645-648, Aug. 1978.*

Supported by: *DOE Contract EY-76-S-02-3566; NSF Grant OCE 77-26084, and Oak Ridge National Laboratory under subcontract 7031, W-7405-ENG-26.*

STABLE-ISOTOPE PALEOCLIMATOLOGY: A POSSIBLE MEASURE OF PAST SEASONAL CONTRAST FROM FORAMINIFERAL TESTS

Werner G. Deuser

Seasonal variations of temperature and salinity in the surface waters of large parts of the oceans are well-established. Available data on seasonal distributions of planktonic foraminifera show that the abundances of different species groups peak at different times of the year with an apparent succession of abundance peaks through most of the year. This evidence suggests that a measure of seasonal contrast is recorded in the isotope ratios of oxygen, and perhaps carbon, in the tests of different foraminiferal species. The evaluation of this potential paleoclimatologic tool awaits planned experiments with recent foraminifera in well-known settings, but a variaty of available data is consistent with the idea that interspecies differences in ^{18}O content contain a seasonal component.

Published in: *DSIR Bulletin 220: 55-60, 1978.*

Supported by: *NSF Grant OCE 73-06586.*

O^{18} and C^{13} CONTENTS OF CARBONATES FROM DEEP SEA DRILLING SITES IN THE BLACK SEA

Werner G. Deuser, Egon T. Degens and Peter Stoffers

Carbonates from three Black Sea drilling sites (Leg 428) were analyzed for their O^{18} and C^{13} contents. The series of 137 samples covers all major environmental stages from the upper Miocene to the present.The material includes detritus and authigenic calcites, aragonites, dolomites, and mangano-siderites. Oxygen isotopes appear to have undergone considerable post-depositional exchange, but carbon isotope data are generally in agreement with paleontological and sedimentological observations which indicate frequent changes in the depositional environment from fresh water to brackish to marine and vice versa since the upper Miocene.

Published in: *Initial Reports of the Deep Sea Drilling Project, Vol. XLII(2): 617-623, Washington, (1978).*

OCEANIC RESIDENCE TIMES OF THE ELEMENTS

Werner G. Deuser

If the present dissolved load of the ocean is at, or close to, an equilibrium state with continental crust, the residence times of all elements in the ocean must be related to one another as their sea water/crust concentration ratios. Derivation or definition of the residence time of one element allows the calculation of the residence times of all other elements. The response times of the elements to perturbations in the equilibrium state are also proportional to their sea water/crust abundance ratios. Since no evidence for major perturbations during the Phanerozoic has been found, it can be assumed that most elements are in a "relaxed" state and that residence times calculated from present sea water concentrations are representative of the past few hundred million years. Possible exceptions are "excess volatiles" of Rubey (1951) which are either still accumulating in the ocean or escaping from crustal rocks long before their surface exposure. A set of residence times was calculated using 1×10^8 years for the residence time of sodium and the most recent values for concentrations of the elements in sea water and average crust. Better values can be caclulated as our knowledge of those concentrations improves. Comparison of these residence times with those calculated from the dissolved river input into the ocean gives an indication of the tendency of the elements to go from the dissolved to the suspended phase, or vice versa, upon mixing of river water with the ocean.

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

MARINE BIOTA, NEARSHORE SEDIMENTS, AND THE GLOBAL CARBON BALANCE

Werner G. Deuser

Nearshore waters to a depth of 200 m constitute only 0.2% of the volume of the world's oceans, but they receive and process 25% of the oceans' input of organic carbon, between 6 and 7×10^{15} g C per year. Man's activities during the past century have significantly increased both the supply of nutrients from land to coastal waters and the total sediment load carried by rivers and deposited in nearshore waters. The combination of increased primary productivity, due to increased supply of nutrients, and increased burial of organic matter, due to increased sedimentation, could sequester a significant fraction of the carbon released into the atmosphere by man as organic carbon in recent shallow-water sediments.

Supported by: *ONR Contract N00014-74-C-0262;NR 083-004 and NSF Grant OCE 76-21280.*

CHEMICAL OCEANOGRAPHIC DATA FROM THE PERSIAN GULF AND GULF OF OMAN

Peter G. Brewer, Alan P. Fleer, Susan Kadar, Deborah K. Shafer and Clarence L. Smith

During February and March of 1976, a major geochemical, biological and geophysical survey of the Persian Gulf and adjacent waters was carried out on R/V *ATLANTIS II*, Cruise 93, Legs 17 and 18. It is the purpose of this report to present the chemical oceanographic data obtained, together with a documentation of the analytical techniques and a simple discussion of the major features observed. Of the 54 hydrographic stations (*ATLANTIS II*, Stations 2357-2410) occupied during Leg 17, 45 may be said to be in the Persian Gulf proper, the remainder being in the Gulf of Oman and the northwestern Arabian Sea.

Published in: *WHOI Technical Report 78- 37. May, 1978.*

Supported by: *NSF Grant OCE 76-22194.*

CONSUMPTION OF DISSOLVED METHANE IN THE DEEP OCEAN

Mary I. Scranton and Peter G. Brewer

Oceanic dissolved methane concentrations are normally in excess of atmospheric equilibrium values in surface waters, but show a rapid decrease with depth. Deep North Atlantic waters have only ca. 30% of their atmospheric equilibrium values of methane and deep North Pacific waters have only ca. 10%. We have calculated methane consumption rates based upon methane analyses and water mass ages derived from published data on $^{3}H/^{3}He$ ages, ^{14}C ages and model calculations. The results show that both methane and oxygen are rapidly consumed in 'young' water but while oxygen consumption continues at a low rate throughout the deep ocean, methane consumption virtually ceases within about 100 years of isolation from the surface ocean.

Supported by: *NSF Grants OCE 75-03731, OCE 76-22194, IDOE Grant OCE-76-81144, NSF Graduate Fellowship and WHOI Education Program.*

DIRECT OBSERVATION OF THE OCEANIC CO_2 INCREASE

Peter C. Brewer

The increase in atmospheric CO_2 of approximately 50 ppm from the mid-nineteenth century to 1972 has led to a corresponding increase in the pCO_2 of sea water. The record of this increase is present in the oceanic water masses, though the signal is obscured. By observing the alkalinity and total CO_2 concentration within a water mass, and stripping off the perturbations of the CO_2 system due to respiration, carbonate dissolution and nitrate addition, the original atmospheric equilibration signal may be recovered. The application of these calculations to GEOSECS (1972) data from the core of the Antarctic Intermediate water reveals propagation of the atmospheric CO_2 signal northwards.

Published in: *Geophysical Research Letters, 5(12): 997-1000.*

Supported by: *NSF Grants IDOE OCE-76-81144 and OCE 76-22194.*

OCEANIC ELEMENTAL SCAVENGING

Wei Min Hao and Peter G. Brewer

The use of one-dimentional advection-diffusion models to describe trace metal data from the deep ocean reveals that for many elements *in situ* consumption occurs. This consumption is usually regarded as being due to scavenging, or adsorption onto sinking particles, and "scavenging residence times", τ_s, have been given for Pb (Craig *et al.*, 1973), Th (Krishnaswami *et al.*, 1976) and Cu (Boyle *et al.*, 1977). We have attempted to reconcile these calculated removal rates with the known abundance and flux of marine particulate matter and to derive the surface chemical properties of marine particulate matter required to produce the observed effects. The calculations are based upon a model proposed by Schindler (1975 a,b) in which interaction with the free M^{2+}_{aq} ion with surface OH-groups is the adsorptive mechanism. Given a particulate matter concentration of 15 µg/kg (Brewer *et al.*, 1976) and settling velocities of 10^{-3} to 10^{-4} cm/sec, we find that surface OH-group concentrations of the order of 10^{4} mole/kg would be required. Since this would require that the surface groups weigh 10^{2} to 10^{3} times more than the particles themselves, we conclude that unless estimates of the particulate flux are seriously in error, sinking particulate matter lacks the capacity to produce the inferred scavenging effect. This is not inconsistent with the conclusions of Bacon *et al.* (1976) who suggested that removal of Pb at the sediment-water interface greatly exceeds that fraction scavenged by particles.

Supported by: *NSF Grant OCE 76-21[illegible] and U.S. Department of Energy Contract EY-77-C-02-3800.*

RADIOCHEMISTRY

SOLUBLE AND PARTICLE-ASSOCIATED FALLOUT RADIONUCLIDES IN MEDITERRANEAN WATER AND SEDIMENTS

Hugh D. Livingston, Susan A. Casso, Vaughan T. Bowen and John C. Burke

From measurements in Mediterranean seawater and sediments, fallout ^{137}Cs, ^{90}Sr and $^{239,240}Pu$ behaved mostly as "soluble" nuclides tracing Mediterranean water movement, whereas ^{55}Fe and ^{241}Am behaved more as "particle-associated" nuclides and were relatively rapidly removed to the sediments. Patterns of nuclide distribution within sediments showed depths of penetration in the order ^{55}Fe > ($^{239,240}Pu$, ^{137}Cs) > ^{241}Am and were thought to result from biological mixing on nuclides whose arrival rates varied in the same order.

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

Pu AND ^{137}Cs IN COASTAL SEDIMENTS

Hugh D. Livingston and Vaughan T. Bowen

Analyses are presented of ^{137}Cs, ^{238}Pu, and $^{239,240}Pu$, in relation to depth in sediment, in 21 gravity cores. These cores span the ranges of times 1964 to 1975, and of water depths 12 to 2000 m; they come from three distinct sedimentation areas off the northeast coast of the United States. Although the ranges of total sediment inventories of $^{239,240}Pu$ and of ^{137}Cs from the various areas hardly overlap, the range of ratios of the inventories of these two nuclides is probably the same in all the areas. In the shallow water cores the ratio $^{239,240}Pu$ to ^{137}Cs regularly diminishes with depth in the core, and a tendency is seen for curves of this function to have similar slopes in each area; ratios of ^{238}Pu to $^{239,240}Pu$ show no change with depth in these shallow water cores. In the deeper water cores, the ratio $^{239,240}Pu$ to ^{137}Cs shows no systematic change with depth, but sometimes the ratio ^{238}Pu to $^{239,240}Pu$ 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 bioturbational process moving the nuclides, together, down into the sediments, of 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.*

Supported by: *Department of Energy Contracts EY-76-S-02-3563 and EY-76-S-02-3379.*

TIME PATTERN OF OFF-SITE PLUTONIUM CONTAMINATION FROM ROCKY FLATS PLANT BY LAKE SEDIMENT ANALYSES

Edward P. Hardy, Hugh D. Livingston, John C. Burke and Herbert L. Volchok

A 50 cm sediment core taken in 1976 from Standley Lake, 7 km east of the Rocky Flats Plant, was sectioned into two-cm segments which were analyzed for ^{137}Cs and transuranic radionuclides. Two independent time lines were developed based upon ^{137}Cs and transuranic peaks representing the 1963 fallout maximum and a high ^{238}Pu to $^{239,240}Pu$ ratio indicating the onset of fallout from the SNAP-9A satellite. The two time lines were identical making it possible to date the core over a 14-year period. A peak in transuranic concentrations occurred in late 1969 which was attributable to contamination from the Rocky Flats Plant. From mass isotopic analysis of plutonium isotopes in selected core segments, the Rocky Flats and global fallout plutonium were differentiated making it possible to estimate that 18 nCi $^{239,240}Pu$ per m^2 from Rocky Flats had accumulated in the sediments. Although this amount represented delivery by both direct deposition of initially airborne material and soil erosion within the watershed, the amount in the sediment through 1970 is reasonable when compared to the plutonium in soil isopleths developed in 1970.

Published in: *U.S. Dept. of Energy Environmental Chemistry Report, July 1, 1978*

Supported by: *Depart. of Energy Contracts EY-76-S-02-3563 and EY-76-S-02-3568.*

FALLOUT RADIONUCLIDES IN MEDITERRANEAN SEDIMENTS

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

Fallout Pu-239, 240 and Cs-137 in a series of Mediterranean sediment cores are independent of depth of overlying water and imply rates of Pu transfer to the sediments slow compared to the Atlantic nuclide inventories and patterns of penetration are interpreted in terms of biological activity within the sediments. High Am-241/Pu-239, 240 ratios suggest that Am sinks 4-9 times faster than Pu.

Published in: *Rapp. Comm. int. Mer Medit., 24:3 (1977).*

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

A MASS BALANCE FOR ^{137}Cs AND ^{90}Sr IN THE NORTH ATLANTIC OCEAN

Stuart L. Kupferman and Hugh D. Livingston

The total inventory of ^{137}Cs (3272 kCi) and ^{90}Sr (2257 kCi) in the North Atlantic Ocean in 1972, as well as the subinventories 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}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^{o} 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.

Twenty-five percent of the ^{137}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}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 $14 \times 10^{6} m^{3}/s$.

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

A PROCEDURE FOR INDEPENDENTLY ESTIMATING BLANKS AND UNCERTAINTIES FOR MEASURED VALUES OF ^{90}Sr AND ^{137}Cs CONCENTRATIONS 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}Sr and ^{137}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}Cs inventories in deep ocean sediments could have accumulated without ever raising concentrations of ^{137}Cs in this tracer-free volume above minimum detactable limits. Several examples are presented to show that reported ^{137}Cs inventories in deep ocean sediments could have accumulated without ever raising concentrations of ^{137}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}Sr and ^{137}Cs data. The method is applicable to any laboratory that has determined ^{90}Sr and ^{137}Cs concentrations in samples collected from within the tracer-free volume.

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

THE TRITIUM-HELIUM-3 METHOD IN HYDROLOGY

Thomas Torgersen, W. Bryan Clarke and William J. Jenkins

The ^{3}H-^{3}He parent-daughter radiotracer pair is discussed in relation to various hydrologic systems. The criteria for evaluating mass spectrometrically obtained ^{3}H-^{3}He measurement and the procedures for calculating a ^{3}H-^{3}He age are described. This age constitutes the mean gas residence time for open systems and the water residence time for closed systems. These measurements can be used to calibrate a wide variety of dynamic parameters and examples of net supply rates, gas exchange rates and vertical diffusivity calculations are given. Data for two meromictic lakes are presented and discussed with respect to groundwater influence. In one lake, groundwater can be ruled out; in the other, it contributes a major source. Possible other uses of this ^{3}H-^{3}He tracer pair in hydrologic systems are discussed.

Supported by: *NSF Grant OCE 76-81774 and NSF and ERDA Grants GB 36348, GA 33124, E 2185 and NGR 33-008-91 (the latter to Lamont-Doherty Geological Observatory).*

ON THE TERRESTRIAL BUDGETS OF HELIUM AND ARGON ISOTOPES AND THE DEGASSING OF THE EARTH

William J. Jenkins

A first-order, bulk degassing model with a time-dependent degassing coefficient is developed for the Earth, using the observed helium isotope fluxes and the uranium budget. The time-dependence of the degassing coefficient is similar to that of radioactive heat production, and the predicted present-day degassing rate ($k = 1.2 \times 10^{-11}\ y^{-1}$) is consistent with observed sea-floor spreading rates. The model satisfactorily predicts the atmospheric ^{40}Ar inventory using a simple model for the ^{40}Ar retentivity for the crust.

Extrapolation of the ratio $^{36}Ar/^{3}He$ to the time of Earth formation yields an approximately chondritic value, suggesting that the apparent terrestrial deficiency in volatiles (esp. ^{3}He) relative to chondrites is due to a bulk, non-fractionating degassing process rather than adsorption-desorption.

Supported by: *NSF Grant OCE 76-81774.*

RADIONUCLIDE RATIOS IN WET AND DRY DEPOSITION SAMPLES FROM JUNE 1976 THROUGH DECEMBER 1977

Muralidhara B. Gavini

^{238}Pu, ^{239}Pu and ^{137}Cs in rain and dry fallout and ^{90}Sr in rain samples were measured at Woods Hole, Massachusetts, from June 1976 through December 1977. The dry fallout was estimated to be about 7.8% of the total deposition of ^{239}Pu and ^{137}Cs. $^{239}Pu/^{137}Cs$ ratios, almost constant at about 0.011 in rain or dry fallout, February through December 1977, suggested that fractionation between the refractory and volatile radionuclides is insignificant in stratospheric fallout. This supports the idea of regional homogeneity of radionuclide ratios in fallout.

Published in: *Earth and Planetary Science Letters, 41: 228-232.*

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

RADIOACTIVE FALLOUT AT WOODS HOLE, MASSACHUSETTS

Muralidhara B. Gavini

^{238}Pu, ^{239}Pu and ^{137}Cs in rain and in dry fallout and ^{90}Sr in rain samples were measured at Woods Hole, Massachusetts, from June 1976 through August 1977. The dry fallout of ^{239}Pu and ^{137}Cs was estimated to be about 7.5% of the total deposition. $^{239}Pu/^{137}Cs$ ratios, almost constant at about 0.011 in rain and in dry fallout, February through August 1977, suggested that particle size fractionation between the refractory and volatile radionuclides is insignificant in stratospheric fallout. The $^{238}Pu/^{239}Pu$ ratio was estimated to be about 0.30 in the tropospheric fallout which resulted from the Chinese nuclear explosion in September 1976, indicating the explosion was characterized by plutonium fission. The $^{238}Pu/^{239}Pu$ ratio decrease, to about 0.025 subsequent to the Chinese nuclear text explosion in November 1976, suggests the explosion was a uranium-triggered fusion device.

Supported by: *Department of Energy Contract EY-77-S-02-3563.*

NATURAL MATRIX STANDARDS

Vaughan T. Bowen

Environmental radiochemistry needs, for use in analytical inter-comparison and as standard reference materials, very large homogeneous samples of a variety of matrices, each naturally contaminated by a variety of longer-lived radionuclides, at several different ranges of concentrations. The reasons for this are discussed, and the minimum assortment of matrices, of radionuclides, and of concentrations is established. Sources of suitable materials are suggested, and the international approach to meeting this need is emphasized.

Published in: *Environment International, 1: 35-39.*

Supported by: *Department of Energy Contracts EY-76-S-02-3563 and EY-76-S-02-3563-A001.*

BACTERIA AND PLUTONIUM IN MARINE ENVIRONMENTS

Anne E. Carey and Vaughan T. Bowen

Microbes are important in geochemical cycling of many elements. Recent reports emphasize biogenous particulates and bacterial exometabolites as controlling oceanic distribution of plutonium. Bacteria perform oxidation/reduction reactions on metals such as mercury, nickel, lead, copper and cadmium. Redox transformations or uptake of Pu by marine bacteria may well proceed by similar mechanisms. On R/V *KNORR* Cruise 69 in September-October 1977, along the continental shelf off Nova Scotia and in the Gulf of St. Lawrence, we obtained profiles of water samples, and sediment cores. Epifluorescent microscopy was used to view bacteria (from water or sediment) after concentration on membrane filters and staining with acridine orange. Radiochemical analyses measured Pu in sediments and water samples. Studies of ^{237}Pu uptake used a strain of *Leucothrix mucor* isolated from a macroalga. Enumeration shows bacteria to range 10^{4}-10^{5} cells/ml in seawater or 10^{7}-10^{8} cells/gram of sediment. These numbers are related to the levels and distribution of Pu in the samples. In cultures of *L.mucor* amended with Pu atom concentrations approximating those present in open ocean environments, bacterial cells concentrated ^{237}Pu slower and to lower levels than did clay minerals, glass beads or phytoplankton. These data further clarify the role of marine bacteria in Pu biogeochemistry.

Supported by: *Department of Energy Contracts EY-76-S-02-2879 and EY-76-S-02-3563.*

LEAD-210 AND POLONIUM-210 AS MARINE GEOCHEMICAL TRACERS: A REVIEW AND A DISCUSSION OF SOME RECENT RESULTS FROM THE LABRADOR SEA

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

Because of their suitable half-lives and their accurately measurable rates of supply to the oceans by decay of parent radionuclides, ^{210}Pb and ^{210}Po have become increasingly important as tracers in the study of marine geochemical processes. Short removal times characterize the behavior of both nuclides in the biologically productive surface layers of the sea. Release from particles at depth is efficient for ^{210}Po, but does not appear to be significant for ^{210}Pb. Scavenging processes in the deep sea are revealed by $^{210}Pb/^{226}Ra$ and $^{210}Po/^{210}Pb$ disequilibria. Adsorption by particles sinking in the water column and reaction at the sea floor both appear to be important removal mechanisms. Data from the Cariaco Trench, an anoxic basin, give evidence of ^{210}Pb transport in both sulfide and oxide phases forming in the water column.

Results from four stations in the Labrador Sea are shown to be consistent with many of the earlier observations. Significant ^{210}Pb depletions, however, are found only at depths greater than 1500 m. Much of the ^{210}Pb inventory in Labrador Sea Water may be maintained by spreading of recently overturned surface water at depth. Below 1500 m $^{210}Pb/^{226}Ra$ ratios decrease steadily with depth to very low values in the Iceland-Scotland Overflow and Denmark Straits Overflow waters. The intense interaction with the sea floor of these water masses may account for this trend.

Supported by: *U.S. Department of Energy Contract EY-77-S-02-3566.*

GEOLOGY and GEOPHYSICS

DEPARTMENT OF GEOLOGY AND GEOPHYSICS

John I. Ewing, *Department Chairman*

GEOLOGY

CHEMICAL VARIATION IN GLASS-WHOLE ROCK PAIRS FROM INDIVIDUAL COOLING UNITS IN HOLES 417D and 418A

Hubert Staudigel, Wilfred B. Bryan
and Geoffrey Thompson

Graphical constructions, least squares calculations, and petrographic observations all indicate that secular crystal accumulation has played an important role in modifying initial liquid compositions. The variation within glass-whole rock pairs can amount to more than the total range observed for the glass compositions.

The cumulate phenocryst assemblages tend to fall into two categories, those in which plagioclase is the only important mineral, and those in which plagioclase is accompanied by olivine and/or pyroxene. The exact nature and extent of the chemical changes depend on the amount and proportions of phenocrysts, but generally involve significant increases in CaO and Al_2O3 and decreases in FeO and TiO_2 in the whole rock data compared to glasses. As is made especially clear by vectors and glass-whole rock pairs plotted in Figure 6, these cumulate phenocryst effects produce considerable scatter in the whole rock data and may significantly change the slope or even the sign of major element covariances in the whole rock compared to the glass data. We conclude from whole rock trace element and major element data, and from microprobe glass analyses, that the magmas at Sites 417 and 418A were formed from a very homogeneous source (by high degree of partial melting) and were subsequently modified by two magmatic processes: shallow level crystal fractionation which yielded the variation in liquid (glass) composition; and by phenocryst redistribution by crystal settling or floating in thick flows and/or dynamic sorting in lava tubes or dikes which yielded the variation in whole rock compositions. This latter process seems to be particularly important in subaqueous lava systems where laminar flow in thin dikes and in lava tubes is more common than trubulent flow, which is less efficient in redistributing phenocrysts. We have shown by calculations and graphic representation that rather small amounts (2-3%) of a mineral of rather extreme composition, such as olivine or titanomagnetite can significantly modify 'characteristic' chemical parameters like FeO, MgO and TiO_2 while plagioclase produces significant variations in Al_2O3 and CaO. These locally-produced compositional changes contribute to the scatter of whole rock data and tend to mask or even to reverse subtle variation trends in the basalt liquids, represented by the glass data. We suggest that these liquid (glass) compositions are much more likely to reflect fundamental magmatic processes; at least they should be easier to interpret as they should have little or no compositional "overprint" due to alteration and crystal accumulation.

The nature of phenocryst assemblages may still provide important clues to physical processes operating on magmas. It is not clear, for example, why phenocryst assemblages should tend to fall into two distinct populations, but such relations have been observed before, for example in the FAMOUS area. Such contrasted populations might arise from mixing of two distinct magmas, or could depend on whether segregation is accomplished primarily by gravity or by a dynamic process such as flow differentiation. It is evident that basalts from Holes 417D and 418A provide many opportinities for more detailed investigation of such processes.

Supported by: *ONR Grant N00014-75-C0291 (Staudigel) and NSF Grant OCE-15858 (Bryan and Thompson).*

DEEP SEA DRILLING PROJECT (DSDP) SITES 417 and 418: A PETROGENTIC SYNTHESIS

Martin F.J. Flower and Wilfred B. Bryan

Major and trace element data for site 417 and 418 are summarized. Plots of TiO_2 and Na_2O vs. MgO indicate that these sites are more like basalts in the FAMOUS area than like basalts from 22-23°N or from sites 395-396. The basalts are consistently depleted in large ion-lithophile elements; in this respect they are geochemically "normal" like those at the modern ridge at 20-23°N.

Chemical differences between basalt glass and corresponding whole rock data are consistent with phenocryst populations in the whole rock samples analyzed. Chemical variation between different magmatic units also appears to involve differential sinking, floating, or dynamic segregation of crystals and liquid during flow. As in other submarine basalt suites, pyroxene appears to be an important crystalling phase, but its rarity as a phenocryst, and its rounded and corroded outlines suggest it is not stable under near-surface conditions. This suggests the magmas evolved by some scheme of polybaric fractionation, with rapid ascent of magma preventing complete re-equilibration.

Publishes in: *Initial Reports DSDP.*

Supported by: *Deep Sea Drilling Project.*

SITE 418 BASALT CHEMISTRY AND MAGMATIC VARIATION

Martin F.J. Flower and Wilfred B. Bryan

Shipboard x-ray fluorescence whole-rock analyses for major elements are discussed and compared. Forty-five samples were considered sufficiently fresh to provide evidence for the nature of original magmatic compositions. These data appear to fall into three distinct chemical groups which can be defined in terms of the approximate range of TiO_2 in each group. These are: group 1, TiO_2 = 1.0-1.2; group 2, TiO_2 = 1.2-1.4; group 3, TiO_2 = 1.4-1.65. Stratigraphic and petrographic criteria, along with data for basalt glasses, allows further subtle subdivisions within these groups. Although there are some oscillations in composition within the sequence, in general group 1 is characteristic of the basalts of the upper 300 m cored, group 2 is typical of the lowermost basalts cored, and group 3 appears at an intermediate position as well as interbedded with other basalts. Overall, seven chemical batches are indicated by combined stratigraphic and chemical criteria.

Although there are some distinct compositional variation trends exhivited by the data set as a whole, there are no definable variation trends within each of the three major chemical groups. The most aluminous compositions appear to reflect accumulation of calcic plagioclase. Other possible crystal-liquid fractionation process will require careful quantitative evaluation; several such studies are presented in papers summarizing shore-based studies.

Supported by: *Deep Sea Drilling Project.*

LOW K_2O DACITE, TONGA-KERMADEC RIDGE

Wilfred B. Bryan

The Dacites from the Tonga-Kermadec island are among the most calcic, siliceous igneous rocks known. They are mineralogically simple rocks, consisting mainly of plagioclase pyroxene, and magnetite, with quartz partly or wholly occult in the groundmass. Geochemically, these rocks are unusually depleted in large ion lithophile elements, and their trace element and isotopic abundance patterns appear to preclude their direct derivation from subducted marine sediments or ocean-floor basalt. The most siliceous examples approach a rhyolitic composition which can be interpreted as a logical end-product of fractional crystallization of a basaltic andesite parent liquid. Whatever processes may be involved, the geologic setting of these islands precludes any contributions from pre-existing continental crust, and these dacites may provide one of the best modern examples of the creation of new continental lithosphere within an oceanic environment.

Published in: *F.Barker, Ed. Tronjkhemites, dacites, and related rocks, USGS Special publication.*

HYPSOMETRY OF THE CONTINENTAL SHELF OFF EASTERN NORTH AMERICA

Kenneth O. Emery

Areas measured between contours at 20-m interval on most of the continental shelf off eastern North America were used to construct histograms and cumulative curves of areas of bottom and volumes of overlying water at various depths. The largest and deepest (212-m to 93-m median depths) shelf provinces are those that have undergone glacial erosion; these have most of the overlying water. More typical of continental shelves of the world are those floored by thick sediments; they have median depths between 27 and 40 m and most are broadly convex in profile between the shore and the shelf break. Also convex upward are the belts between the shore and the -100-m contours and the belt between -20 m and 20 m above sea level. However, the belt between the +20-m and +100-m contours and the broader one between the -100-m and +100-m contours are concave upward. This geometry is about what would be expected from the known history of marine erosion and deposition on a relatively submergent coast.

Supported by: *Henry Bryant Bigelow Oceanographic Chair.*

GENERAL IMPLICATIONS OF THE LEG 49 DRILLING PROGRAM ON NORTH ATLANTIC OCEAN GEOLOGY

Bruce P. Luyendyk, Alexander Shor, and Joseph R. Cann

General geological results of the Leg 49 drilling program are discussed without emphasis on petrologic and geochemical data. Three holes were drilled on the west flank of Reykjanes Ridge (407, 408, 409). Our results suggest that the ridge has been anomalously shallow relative to the worldwide average ridge depth since at least 36 myBP (anomaly 13). However, it is clear that thermal or tectonic events during the past 17 million years have perturbed the ridge depth profile, and perhaps bias the simple backtracking results for older crust to anomalously shallow paleodepths. A possible regional uplift containing an average vertical component of up to 25 meters per million years since 36 myBP cannot be entirely excluded based on our results.

Other holes were located close to the crest of the Mid-Atlantic Ridge (410 and 410A) or in the rift valley itself (411). None of the ridge crest sites (including 409) showed evidence of hydrothermal alteration and all rocks were extremely fresh. However, magnetic properties show evidence of oxidation of 410A basalts. Generally, all sites show a degree of alteration which is strongly correlated with age, which suggests long-term reaction between basalts and cold sea water. Two sites (412 and 413) were located in fracture zone B in the FAMOUS area. The rocks here were generally fresh and unaltered basalts similar to rocks recovered from the rift mountains by dredging and during Leg 37. Even though sites 412 and 413 are on opposite sides of the fracture valley, they are both the same age, and match the age of the magnetic anomaly on the young side of the valley.

Supported by: *Deep Sea Drilling Project.*

BOTTOM CURRENTS AND ICE RAFTING IN THE NORTH ATLANTIC: INTERPRETATION OF NEOGENE DEPOSITIONAL ENVIRONMENTS OF LEG 49 CORES

Alexander N. Shor and Richard Z. Poore

DSDP (Deep Sea Drilling Project) Leg 49 provides new data bearing on two important problems concerning the Neogene environment of the North Atlantic. Our interpretation of three northern sites (407, 408, and 409) supports previous interpretations based on Leg 38 data which conclude that the deep circulation of the eastern North Atlantic (and possobly the entire North Atlantic) did not attain its present configuration until at least the early Miocene. This is considerably younger than previous studies had suggested. For example, Berggren and Hollister (1974, 1977) inferred a deep connection between the Norwegian Sea and the North Atlantic approximately 50 mybp.

The second problem of interest to geologists and climatologists is the maximum southward extent of ice rafting in the North Atlantic during the Pliocene, and the age of initiation of ice rafting. Data from Site 410 (45°N latitude) provide a minimum southern limit for the Pliocene iceberg drift and supports the age of 3 mybp of Berggren (1972) for the initiation of extensive Northern Hemisphere glaciation.

This paper discusses aspects of these two problems based on data from Leg 49 and from other recent studies in the North Atlantic (DSDP Legs 12, 38 and 48).

Supported by: *Deep Sea Drilling Project.*

THE RED SEA - THE OCEANOGRAPHY OF A SEMI-ENCLOSED SEA

David A. Ross

The Red Sea is an elongated basin that is being formed by the process of seafloor spreading. Bottom topography consists of smooth shelves separated by a large, central main trough, that itself has a deep and deformed axial valley.

The Red Sea is bounded by topographically high areas that influence the weather and generally restrict atmospheric circulation parallel to the axis of the sea. Climate is arid and hot and evaporation is of the order of 200 cm/year. North of 19°N the winds are generally from a north to northeasterly direction; to the south their direction will change according to the monsoons. From October to May winds are mainly from the southeast, while during June-September they are mainly from the northwest. The combination of climate, low river runoff and rainfall, high evaporation rate and restricted circulation has produced relatively dense, high temperature (up to 30°C) and high salinity (40 °/oo or more) water.

The general circulation pattern of the Red Sea shows very distinct seasonal changes that are primarily influenced by prevailing winds and to a lesser extent by seasonal changes in density and evaporation. In the winter (October-May) surface flow is to the north coming in from the Gulf of Aden and subsurface flow is to the south. This pattern will reverse in the summer. Upwelling can occur in the northern part of the sea during the summer months, but sinking of dense water occurs in the winter period. The renewal time for the upper 150 m of Red Sea water may be as little as six years, whereas for the entire Red Sea a value of about 200 years may be more appropriate.

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

THE STRATIGRAPHY AND STRUCTURE OF THE LAURENTIAN CONE REGION

Elazar Uchupi, James A. Austin, Jr., and David A. Ross

A series of single- and multi-channel seismic reflection profiles combined with well data from the adjacent shelves and deep sea and published geophysical profiles permit the reconstruction of the geologic development of the Laurentian Cone. The Cone's sediments can be divided into two megasequences, a lower one of Early Jurassic to Eocene age, which extends from a transitional and oceanic basement to Horizon A^T, and an upper sequence of early/middle Miocene to Holocene

age extending from Horizon A^T to the sea floor. Sediments of the lower megasequence appear to have been deposited under uniform tropical-sub-tropical climatic conditions. Plastic flow of Early Jurassic salt at the base of the lower megasequence has resulted in the deformation of the strata above, and the formation of a ridge that extends along the continental rise from Georges Bank to the Grand Banks. Horizon A^T separating the two sequences is the surface of a fan deposited by turbidity currents during a latest Cretaceous and a late Eocene/Oligocene regression; these regressions are due to the onset of continental glaciation. Deposition of this regressive wedge initiated the emplacement of the Laurentian Cone. The upper terrigenous megasequence, composed of three coalescing fans, was emplaced through the action of turbidity currents, and reflects the rapidly fluctuating climatic conditions associated with the waxing and waning of continental glaciers from latest Miocene to Holocene. The cone is not being supplied with sediments from the continent at present, but sediment continues to move down-cone in response to sporadic seismic activity.

Supported by: *NSF Grant OCE76-82146.*

COMPOSITIONAL LAYERING IN ALPINE PERIDOTITES: EVIDENCE FOR PRESSURE SOLUTION CREEP IN THE MANTLE

Henry Dick and John Sinton

Field evidence from the Josephine (southwestern Oregon) and Red Mountain (New Zealand) peridotites indicates that compositional layering in alpine-type peridotites pre-dates emplacement into the crust, and is dissimilar in origin to layering in stratiform intrusions. Field, geochemical and textural evidence all suggest that the layering formed during anatexis and upward flow of the peridotite in the mantle. A cumulus origin for the layering is rejected as there is strong geochemical evidence to suggest that alpine-type peridotites are the residues of partial fusion in the mantle. Although the layering superficially resembles layering in stratiform intrusions, there are no other features present which suggest a magmatic origin. The orientation of the layering, however, closely resembles that of strain-slip (or crenulation) cleavage in the axial zones of old mountain belts suggesting a deformation related origin. It also appears unlikely that the layering is solely the product of a mechanical segregation accompanying deformation ("flow layering") inasmuch as evidence for prolonged high-temperature creep of the peridotites is found throughout the entire peridotite whereas the layering is not. The most likely mechanism for the origin of the layering appears to be metamorphic differentiation accompanying deformation, pressure solution creep and anatexis of the peridotite. This suggests that pressure-solution creep is a principal creep mechanism in areas of ascending athenosphere such as below mid-ocean ridges.

Supported by: *NSF Grants OCE77-22658 and DPP77-21208.*

DISRUPTION OF THE FENI SEDIMENT DRIFT BY DEBRIS FLOWS AND ASSOCIATED TURBIDITY CURRENTS FROM ROCKALL BANK

Roger D. Flood, Charles D. Hollister, and Peter Lonsdale

Slumping on the eastern margin of Rockall Bank approximately 15,000 to 16,000 years before present produced a series of debris flows and turbidity currents which have disrupted the Feni Drift around 56°N 13°W. Near-bottom investigations with a deeply-towed instrument package show that a large area of slightly irregular hyperbolic echoes (11,000 km^2) on the Feni Drift reflects the presence of a large debris flow. Sediment cores indicate that turbidity current deposits are present over a large area. The irregular topography of the debris flow results from large blocks of relatively undisturbed sediments protruding from the surface of the flow on the shallower, erosional portion of the flow. The irregular topography on the deeper, depositional portion of the flow is due to folded sediments. This debris flow obliterated part of a field of sediment waves, the northern portion of which now forms the northern boundary of the debris flow. Near-bottom investigations indicate that these sediment waves were inactive at the time of slumping, sediments were rapidly filling in the wave troughs, suggesting that a large amount of sediment had been deposited in the area before slumping occurred.Possibly the large influx of sediment in the last glacial period, combined with increased wave activity during lower sea level stands, overloaded these sediment slopes and made them more susceptible to failure.

Supported by: *NSF Grants DES-73-06651 and OCE76-22152; ONR Contract N00014-74-C-0262; NR 083-004.*

MORPHOLOGY OF SEAMOUNTS IN THE WESTERN PACIFIC AND PHILIPPINE BASIN FROM MULTI-BEAM SONAR DATA

Charles D. Hollister, Morris F. Glenn, and Peter F. Lonsdale

New multi-beam bathymetric data from the Philippine Sea and Northwest Pacific Basin reveal linear chains of small (less than 40 km^3) domed-shaped volcanoes (Philippine) and coned-shaped volcanoes (Pacific) rising 100 to 1000 m above the 6 km deep ocean floor.

Some appear to have well-developed collapsed calderas and spines. Their morphology suggests recent formation in supposedly stable mid-plate regions and their occurrence in linear chains approximately parallel to plate motion may suggest an origin by extrusion from "mini-hot spot" plumes.

Published in: *Earth and Planetary Science Letters* 41: 405-418, 1978,

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

OFF-RIDGE VOLCANISM AND SEAFLOOR SPREADING IN THE SHIKOKU BASIN

George Klein, Henry J.B. Dick, *et al.*

The nature of the crust and origin of marginal basins of the western Pacific continue to be of widespread interest to earth scientists. Recent advances in mapping magnetic anomalies and drilling basement rocks in these areas have suggested that marginal basins are floored by ocean crust and formed by conventional seafloor spreading processes from a mid-basin ridge. Our drilling results in the Shikoku Basin during Leg 58 of the Deep Sea Drilling Project reported here indicate that this basin formed as a consequence of back-arc spreading, but that the original simple spreading hypotheses need reappraisal because the crustal stratigraphy and so-called basement age relationship are more complex than expected.

Published in: *Nature, Vol. 273 (5665): 746-748, June 29, 1978,*

Supported by: *Deep Sea Drilling Project.*

PLASTERING AND DECORATING IN THE NORTH ATLANTIC

Charles D. Hollister, Roger Flood, and Ian Nicholas McCave

Vast areas of the deep-sea floor are decorated with distinctive sediment bed forms that have been produced by strong, near-bottom currents. These forms and currents are important because, on a practical level, our understanding of their construction and routes can have a direct bearing on the selection of sites for the disposal of toxic wastes in the deep sea, and may also be applied to exploration for minerals, oil, and gas. On a theoretical level, the features provide a long-term geological record of seabed current activity, a record that would be impossible to obtain through conventional measurement techniques, such as current-meter moorings. Bed and current records are obtained by using a combination of observations from submersibles, surface ships, and such vehicles as Scripps Institution of Oceanography's *Deep Tow* device (see *Oceanus*, Spring 1977). The bed forms range in size from regular, sinusoidal mud waves several kilometers between crests and tens of meters high to very small lineations measured in centimeters. Ripple patterns also have been detected in bottom photographs at depths of more than 5,000 meters.

When these patterns were first observed, it was thought that the abyss was generally a tranquil region with little to disturb the gentle rain of particles from above. It did not seem possible to some that these patterns were produced by strong, near-bottom currents. There are, of course, vast areas (in the middle of great oceanic plates and beneath the major surface circulation gyres) where tranquility, perturbed only by the gentle probings of a wide variety of benthic organisms, is the rule. But recent observations, utilizing sophisticated deep-sea instruments, reveal that considerable commotion prevails near the edges of ocean basins and in regions where bottom water is produced.

Published in: *Oceanus* 21: 5-13, *1978.*

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

PARTICULATE CALCIUM CARBONATE IN NEW ENGLAND SHELF WATERS: RESULT OF SHELL DEGRADATION AND RESUSPENSION

Michael G. Fitzgerald, Carol M. Parmenter and John D. Milliman

Aragonite and calcite needles, 30 to 500 μm long, are prominent visual components throughout the water column in some areas of the New England shelf during winter months. Further investigation shows these "needles" to be laths derived from the degradation of mollusk shells which are resuspended from bottom sediments during winter storms. Such degradation and subsequent transport/dissolution of carbonate particles may help explain why the terrigenous "starved" shelf sediments off New England contain such small amounts of calcium carbonate.

Supported by: *NOAA Sea Grant and U.S. Geological Survey 15615.*

MORPHOLOGY AND STRUCTURE OF THE UPPER AMAZON CONTINENTAL MARGIN

John D. Milliman

Integration of extensive geophysical data (seismic refraction, reflection, gravity and magnetic) with geologic information derived from exploratory drilling and land-based studies allows the delineation of four major phases of development of the Amazon continental margin. Early rifting during the Creta-

ceous separated a Precambrian craton in the Amazon region from its counterpart in Liberia: Eburnian/Trans-Amazonian (1800-2000 m.y.) magnetic anomalies, however, are still evident on both margins. During rifting, or perhaps soon after, the Amazon graben was formed, possibly augmented by intersection of the St. Paul's Fracture Zone onto the Amazon margin.

During the Cretaceous and Paleocene, terrigenous sediments were derived primarily from the erosion of nearby shield rocks. Depositional environments ranged from continental to shallow marine, the depocenter being the Marajo Basin. Occurrence of shelf-edge carbonates suggests that terrigenous sediments were prevented from escaping to the deep sea (perhaps by shelf-edge reefs) and remained primarily on the inner shelf.

Uplift and subsequent erosion of the Andes during the Niocene provided 60-fold increase in terrigenous influx, which overwhelmed the shelf-edge barriers and began formation of the Amazon Cone. Accumulation since this time has accounted for as much as 12 km of sediment.

Quaternary fluctuations in sea level have caused two distinct phases of margin sedimentation. During glacially lowered sea level, Amazon sediment emptied directly into the adjacent outer margin, resulting in high accumulation rates. During high sea level stands, such as at present, sediment is transported NW along the inner shelf, with little material escaping to the outer shelf or beyond.

Supported by: *NSF Grants I.P.O.E. GX41960 and GX48723.*

COMPOSITIONAL VARIATION IN A STEADY-STATE ZONED MAGMA CHAMBER: MID-ATLANTIC RIDGE AT 36°50'N

Wilfred B. Bryan, Geoffrey Thompson and Peter Michael

Basalt glasses collected in the FAMOUS dive area by the submersible *ALVIN* have been analyzed for B, Li, Cr, Ni, Co, Cu, Ga, Sr, Ba, V, Y, and Zr by optical emission spectrography. Field relations, petrography, and other published trace element data are reviewed. Published partition coefficients are combined with least-squares estimates of mineral proportions to compute variations expected for postulated equilibrium crystallization in a high-level, zoned magma chamber. Variation in Cr, Ni, Co, and Cu is consistent with such a process, involving crystallization of plagioclase, pyroxene, olivine, and sulphide. The other elements are enriched by factors from about 1.5 to 4.0 times the amounts predicted by this model; the excess enrichment is greatest for Ba and least for Y and V. These excess enrichments may in part reflect the progressive accumulation of incompatible elements in the margins of a steady state magma chamber, and may also reflect variations in initial concentrations in successive batches of mantle-derived parent liquid.

Supported by: *NSF Grant OCE76-00234.*

STRUCTURE AND ORIGIN OF THREE CONTINENTAL MARGIN PLATEAUS, NORTHEASTERN BRAZIL

Roberto Fainstein and John D. Milliman

The narrow continental terrace of northeastern Brazil is marked by three plateaus, each 30-70 km wide. Preliminary geophysical and dredge data indicate that all three lie along E-W trends connecting oceanic fracture zones and continental lineaments and/or areas of post-rifting volcanism/tectonism. Although the Pernambuco Plateau is flanked by prominent basement highs (presumably partly related to oceanic fracture zones), both it and the Rio Grande do Norte Plateau overlie stretched continental crust. In constrast, the Ceara Plateau is a limestone-capped seamount on the western end of the Fernando de Noronha Ridge, and may be as young as 1-30 m.y.

Supported by: *NSF Grant IDO76-8723.*

THE GEOLOGIC HISTORY OF THE PASSIVE MARGIN OFF NEW ENGLAND AND THE CANADIAN MARITIME PROVINCES

Elazar Uchupi and James Austin, Jr.

The geologic history of the passive continental margin off the east coast of North America from New England to Newfoundland is described using all available geological and geophysical information. "Rift" and "drift" phases of the margin's evolution are recognized, with rifting iniated in Late Triassic and completed by Early Jurassic. The plate decoupling process created a complex block-faulted terrain as a result of uplift and tensional fracturing. The approximate plane of continental separation is marked by a "hinge zone" characterized by a pronounced steepening of basement gradients. Since the Early Jurassic, the margin has undergone continual subsidence in response to cooling and sediment loading. This "drift" sequence attains its maximum thickness in the vicinity of the continental slope, and thins both landward and seaward. On the shelf, this unit consists of Mesozoic evaporites, carbonates, and deltaic deposits. Overlying these sediments is a prograding wedge of Cenozoic clastics. On the rise, the Mesozoic sediments are evaporites, hemipelagic limestones and shales, and carbonaceous clays. The Cenozoic is dominantly terrigenous material.

Separating these two sedimentary provinces is the continental slope, a site of major facies changes and a Mesozoic reef complex.

Supported by: *NSF Grant IDOE 74-09421; NOAA Sea Grant; U.S.State Department and Ocean Industry Program.*

SITE 417 BASALT CHEMISTRY AND MAGMATIC VARIATION

Wilfred B. Bryan and Martin F.J. Flower

Shipboard x-ray fluorescene analyses for major elements are discussed and compared; data for significantly altered rocks have been deleted in order to determine the nature of original magmatic trends and groupings. For hole 417A, six analyzed samples are considered fresh, while 29 samples from hole 417D were retained. At site 417 these data do not define distinct compositional groupings but represent a spectrum of compositions in which TiO_2 covers a range from 1.15 to about 1.65 weight $^{o}/_{oo}$. This range overlaps the fields of the three major basalt groupings from site 418. Petrographic criteria do, however, suggest three groupings based on phenocryst content. These are: a three-phase plagioclase-olivine-pyroxene phyric group; a plagioclase-olivine phyric group; and a plagioclase phyric group. The aphyric or nearly aphyric basalts lie toward the high TiO_2 end of the data distribution. Both petrographic observation and comparison of CIPW normative mineral assemblages suggest that most of the major element variation is due to variation in the proportions and total amounts of phenocryst phases.

Published in: *Initial Reports, DSDP.*

Supported by: *Deep Sea Drilling Project.*

RELICT OYSTERS ON THE UNITED STATES ATLANTIC CONTINENTAL SHELF: A RECONSIDERATION OF THEIR USEFULNESS IN UNDERSTANDING LATE QUATERNARY SEA-LEVEL HISTORY: A DISCUSSION.

Kenneth O. Emery and Arthur S. Merrill

A reply to objections by Macintyre, Pilkey, and Stuckenrath regarding criteria and subfossil species to be used for radiocarbon dating of Holocene sea levels.

Supported by: *Henry Bryant Bigelow Oceanographer Chair.*

REGIONAL VARIATION AND PETROGENESIS OF BASALT GLASSES FROM THE FAMOUS *AREA, MID-ATLANTIC RIDGE*

Wilfred B. Bryan

Basalt glasses and minerals from precisely located dredge and submersible stations in the *FAMOUS* area have been analyzed by electron microprobe, and their regional relationships and petrographic features are described. Samples from the median valley south of fracture zone B, and from the walls of the valleys north and south of fracture zone B, tend to show higher K_2O, TiO_2, and FeO/MgO than samples from the active volcanic centers in the northern median valley. Some fracture zone samples are high in K_2O relative to median valley basalts. All glasses define an apparent binary cotectic in the normative Plagioclase-Pyroxene-Olivine ternary, suggesting compositional control by low-pressure crystal-melt equilibria. Correlations of FeO/MgO between pyroxene and glass and olivine and glass suggest that most crystals are in equilibrium with their liquids; a few xenocrysts depart significantly from equilibrium. Plagioclase compositions are much less well-correlated with liquid composition.

The total range of variation of *FAMOUS* basalt glasses approaches that of all glass samples from spreading centers in the Atlantic. The high FeO/MgO, high TiO_2 glasses have been thought to be typical of the East Pacific Rise, but other examples are known from the Atlantic at 22-23°N. The submersible samples, which have been described in other papers, define the low TiO_2, low FeO/MgO end of the total distribution.

Model calculations indicate that high level fractional crystallization can account for those subsets of parent-residual liquids which show a ratio of increase of FeO/MgO to TiO_2 of about 1.5 to 1.0. Postulated parent-residual pairs in which TiO_2 enrichment is greater than FeO/MgO enrichment also show excess K_2O enrichment; this feature is characteristic of many other tested parent-residual pairs among seafloor basalts, and of submersible samples from the *FAMOUS* dive area. These TiO_2-enriched samples may be derived from a zoned magma chamber, as previously suggested, or may have been produced directly by mantle-related processes not yet well-defined. The K_2O-enriched basalts from fracture zone B also may represent a distinct magma type erupted within the fracture zone.

Supported by: *NSF Grant IDO 75-00294.*

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

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_2 > 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 chondrite-normalized REE patterns.

Quantitative models, involving major and trace element abundances and phase compositions, demonstrate: (1) In terms of most major elements and phase composition Site 214 and 216 ferrobasalts can be related by fractionation involving clinopyroxene and plagioclase from the more basic Site 214 liquids. However, the contents of Ti, K, Zr and light-REE in Site 216 basalts are greater than implied by the fractional crystallization model. This excess may reflect primary characteristics arising during the partial melting process. (2) The basalts from Site 214 can be related to the overlying oceanic andesites by a fractionation model involving removal of clinopyroxene and plagioclase, and subsequent fractionation of magnetite. (3) Site 254 basalts, at the southern end of the ridge, and the Amsterdam-St.Paul volcanic province are inferred to represent the most recent activity associated with the hot-spot forming the 90°E Ridge. A liquid parental to the ferrobasalts of Sites 214 and 216 is considered to have a composition intermediate to that of incompatible element depleted mid-ocean ridge tholeiites and incompatible element enriched island tholeiites similar to those of Site 254 and the Amsterdam-St. Paul volcanic province.

Supported by: *NSF Grants DES 74-00147 and 00268.*

BASALTS AND RELATED ROCKS FROM DEEP-SEA DRILLING SITES IN THE CENTRAL AND EASTERN INDIAN OCEAN

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

Petrological and geochemical data are presented for basement rocks recovered from thirteen sites (211,212,213,214,215,216,253, 254,256,257,259,260 and 261) drilled on Legs 22,26 and 27 of the Deep Sea Drilling Program. Basalts from Sites 212,213,253,257,259 and 261 have petrographic and geochemical characteristics of tholeiitic basalts from active spreading ridge axes in the major ocean basins.

Except for the lower basalts at Site 253, all the basement rocks from four Ninetyeast Ridge sides (214,216,253,254) are similar to oceanic island tholeiitic sequences such as on Amsterdam-St.Paul Islands. The geochemical data for the Ninetyeast Ridge rocks are consistent with the development of this ridge as a hot-spot trace.

Basalts from deep ocean Sites 216 and 256 have geochemical characteristics more akin to tholeiitic basalts from spreading ridge axes close to major volcanic islands, i.e. they have high large ion lithophile element abundances relative to tholeiitic basalts found at spreading ridge axes away from islands.

Alkali olivine basalts were recovered from Site 211 and they contain abundant amphibole. They are related to the volcanism which created the Cocos-Keeling-Christmas shoal areas.

Published in: *Marine Geology, 28:113-138, 1978.*

Supported by: *NSF Grants DES74-00268 (WHOI) and DES74-00147 (MIT).*

PETROLOGIC CHARACTER OF THE ATLANTIC CRUST FROM DSDP AND IPOD DRILL SITES

Wilfred B. Bryan, Geoffrey Thompson, and Frederick A. Frey

Basement rocks recovered by DSDP and IPOD drilling in the Atlantic are predominantly pillowed or massive basalt lava flows which resemble modern Mid-Atlantic Ridge (MAR) basalts in their range of chemical composition and petrographic characteristics. Basalts from the oldest sites drilled (70-150 m.y.) generally resemble modern basalts presently being erupted at the locations on the MAR where these older basalts should have originated; all of these represent "normal" ridge segments unaffected by "mantle plume" activity.The Leg 37 transect drilled opposite the Azores "mantle plume" or "blob" shows evidence of some fluctuation in geochemical parameters, possibly indicating short-term fluctuations in plume activity.

Only two sites (334 and 395) have penetrated layer 3 plutonic rocks, but it is likely that these are tectonically emplaced, and the true thickness of layer 2 has not been defined by drilling. In general, the transition from sediment to basalt basement is sharp. Excellent core recovery at Sites 417 and 418 shows that pillowed and massive flows are interbedded; dikes and sills are rare at these and other sites, but probably are hard to recognize unless core recovery is very good. Drilling at Site 417 suggests that intense low temperature alteration may be limited to topographic highs which are not immediately buried by sediment. Hydrothermal alteration and metamorphism are not encountered in the sites so far drilled.

Most DSDP and IPOD sites have not been well-placed to indicate the persistence of "mantle plumes" with time, although north-south geochemical variations in continental triassic basalts resemble those documented for modern basalts associated with the Azores plume and suggest that such plumes may have initiated spreading in the Atlantic. Future

drilling should be designed to define the persistence of such plumes in time and space, and also should attempt to penetrate the lower part of layer 2 and the upper part of layer 3 in a crustal section of normal thickness.

Supported by: *NSF Grant DES 76-15858.*

ACTIVE DEEP SEA SEDIMENTARY FURROWS

Roger D. Flood and Charles D. Hollister

Bed forms in cohesive sediments have been observed and sampled by submersible on the Blake-Bahama Outer Ridge. These features, ranging from ripples to furrows, have developed as a result of deep current activity. Furrows have been depositional for at least the last 11,000 years in one area investigated and are erosional in the other. Morphological variation may reflect variations of sediment supply.

Supported by: *ONR Contract N00014-75-C-0208;NR 083-004.*

CRUISE DATA REPORT, R/V ATLANTIS II *93 LEG 7*

Robert C. Groman and James A. Dunworth

Summary charts and tables of the underway and station data collected during the R/V *ATLANTIS II* Cruise 93 Leg 7 are presented. The ship left Port Louis, Mauritius, 8 April 1976 on a 29 day geophysical and geological survey in the Mascarene and Somali Basins in the Western Indian Ocean. Seventeen piston cores were successfully recovered in the Mascarene Basin, Amirante Trench and Somali Basin regions. Single channel continuous seismic profiles were made on 2920 km of ship's track in the Somali Basin. Echo soundings, total geomagnetic field and gravity field data were collected throughout the entire leg. The R/V *ATLANTIS II* arrived in Mombasa, Kenya on 6 May, 1976.

Supported by: *ONR Contract N00014-74-C-0208;NR 083-004 and NSF Grant OCE75-21588.*

DEEP THERMOCLINE 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 (~90 km) topographic gap near 09°S, 52°E [illegible] restricts the flow of the deep western boundary current (DWBC) from the Mascarene [illegible] into the Somali Basin in the western [illegible]ean. Seismic reflection profiles, [illegible]ograms, nephelometer profiles, [illegible] data, bottom photographs, and [illegible]ow that deposition of sedi[illegible] passage below ~3300 m is controlled by relatively strong flow of the DWBC. The channel axes contain highly reflective, horizontally-stratified deposits whose acoustic character indicates erosion and/or non-deposition. Thick (up to 0.5 sec), acoustically transparent drift deposits and sediment waves are widespread across the lower flanks of the adjacent ridges and along the channel margins. Current flow appears to be strongest in the channel axes, and becomes progressively weaker toward the channel margins. The regional distribution of drift deposits (depositional regime) and channel deposits (erosion or non-depositional regime) indicates a western intensification of the DWBC flow within the passage. Moreover, the presence of steep, asymmetrical ripples, strong scour, and highest light-scattering values in the Western Channel suggests that the DWVC flow may be most intense within the Western Channel, even though this channel has the shallowest sill depth of any of the channels in the passage. Drift deposits overlie channel deposits at several locations in eastern channels, and manganese pavements occur at shallow sub-bottom depths east of the present-day DWBC axis, suggesting that the DWBC flow may have been broader and/or more intense during the geological past.

Large fields of well-developed abyssal sediment waves, with heights of tens of meters and wavelengths up to a few kilometers, flank the Western Channel. These bedforms are best developed only at the channel margins, and only within a narrow depth interval which corresponds approximately with that of the near-bottom mixed layer (~3800 to 4000 meters). The lithology, micro-relief, subbottom stratification, and regional distribution of the sediment waves suggests that they are constructional bedforms produced by deposition from the DWBC within the Western Channel. Reflection profiles indicate that net accumulation rates increase systematically outward from the channel axis. The sediment waves may thus reflect, and perhaps may be a consequence of, a strong horizontal velocity shear at the channel margins. The presence of well-formed sediment waves in biogenic ooze suggests that proximity to large supplies of terrigeneous sediment (i.e., turbidity current channels) may not necessarily be required for the generation of wave-like bedforms on this scale.

Supported by: [illegible]

GEOPHYSICS

MARINE MAGNETIC ANOMALIES, GEOMAGNETIC FIELD REVERSALS, AND MOTIONS OF THE OCEAN FLOOR AND CONTINENTS

James R. Heirtzler

This paper summarizes the results of the three previous papers in this series, which have shown the presence of a pattern of magnetic anomalies, bilaterally symmetric about the crest of the ridge in the Pacific, Atlantic, and Indian Oceans. By assuming that the pattern is caused by a sequence of normally and reversely magnetized blocks that have been produced by sea floow spreading at the axes of the ridges, it is shown that the sequences of blocks correspond to the same geomagnetic time scale. An attempt is made to determine the absolute ages of this time scale using paleomagnetic and paleontological data. The pattern of opening of the oceans is discussed and the implications on continental drift are considered. This pattern is in good agreement with continental drift, in particular with the history of the break-up of Gondwanaland.

Supported by: *Joint Oceanographic Institutions, Inc.*

RELATIVE RATES OF MOVEMENT OF THE OCEAN CRUST

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 may be at a rate of 40 km/m.y. for short periods of time. Broader thermal cooling drops the ridge at a rate of about 175 m/m.y. for 1 m.y. old crust, and at a rate of about 20 m/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 to 40-60 km/m.y. on a Wadati-Benioff zone which dips at 45°.

Seamounts subside at a rate of 20-60 km/m.y. which is comparable to the rate subsidence in some Wadati-Benioft zones, and comparable to sea floor spreading rates, and much more than the subsidence due to cooling of the oceanic crustal plates.

Supported by: *Joint Oceanographic Institutions, Inc.*

THE ARGO ABYSSAL PLAIN

James R. Heirtzler, Peter Cameron, Peter J. Cook, Thomas Powell, Hans A. Roeser, Sutesna Sukardi and John J. Veevers

Eighteen geophysical transects were made in the Argo Abyssal Plain to study the magnetic anomalies, bathymetry and seismic structure. Magnetic anomalies were identified as being the Mesozoic anomalies M-10 to M-25, increasing in age from the Java Trench to the northwest continental shelf of Australia. A new bathymetric map shows that the Argo Abyssal Plain is bounded by the 5600-m contour and reaches a maximum depth of 5730 m against the inshore side of the Exmouth Plateau. Joey Rise was found to limit the Argo Abyssal Plain on the southwest. Continuous seismic profiles, sonobuoy data and seismic data from other cruises permit one to contour the depths to oceanic basement. Numerous diapir-like structures were observed,but their nature and origin is obscure.

Published in: *Earth and Planetary Science Letters, 41 (1978):21-31.*

Supported by: *NSF Grant OCE78-20074.*

DEEP-OCEAN DRILLING

James R. Heirtzler and Arthur E. Maxwell

The International Program of Ocean Drilling (IPOD) - a joint research effort that has just completed a decade of important work - is at a critical juncture in its development. The marine scientific community is pausing to assess the many accomplishments of the program as well as objectives not obtained. In short, it is trying to determine whether drilling should continue, and if so, how and at what cost. Among the significant results of the program - which has been compared in importance with the first *Challenger Expedition* (1872-1876) that ushered in modern oceanography - have been data that support the theory of sea-floor spreading or plate tectonics, and indications of oil and metal deposits in the sediments at various coring sites. In addition, important information has been gathered relating to past climate periods - for example, it has been established that Antarctic glaciation has lasted more than 20 million years, or more than four times the age previously accepted. But the *Glomar Challenger* - the ship specially built for the project that has been used to drill more than 703 holes at 466 sites (as of Leg 61), along with sampling, measuring, and charting that has filled 42 volumes with data on underwater structure and sediment and basement rock composition - is generally felt not adequate to meet the deeper and more demanding drilling of the 1980s. And so thought is turning to use of a larger vessel - probably the salvage

ship *Glomar Explorer* - to conduct the major drilling efforts of the next decade. Thus it is appropriate here to review the early years of the program, addressing the questions relevant to its future direction.

Published in: *Oceanus, Vol.21(3),1978.*

Supported by: *Joint Oceanographic Institutions, Inc.*

THE KANE FRACTURE ZONE IN THE CENTRAL ATLANTIC OCEAN

Graham M. Purdy, Philip D. Rabinoqitz, and Jan J.A. Velterop

The Kane fracture zone has been traced as a distinct topographic trough from the Mid-Atlantic Ridge near 24N to 80 mybp isochron (magnetic anomaly 34) on either side of the ridge axis for a total of approximately 2800 km. Major changes in trend of the fracture zone occur at approximately 72 mybp (anomaly 31 time) and approximately 53-63 mybp (anomaly 21-25 time) which are the result of major reorientations in spreading directions in the central Atlantic Ocean.

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

AN OCEAN BOTTOM HYDROPHONE INSTRUMENT FOR SEISMIC REFRACTION EXPERIMENTS IN THE DEEP OCEAN

Donald E. Koelsch and Graham M. Purdy

Tests of a new Ocean Bottom Hydrophone (OBH) instrument have recently been completed at Woods Hole Oceanographic Institution. This instrument is designed to float ~ 3 m above the sea flocr at depths of up to 6100 meters for periods of up to 10 days and continuously records the output of a single hydrophone on a four-channel 1/40 i.p.s. analog magnetic tape recorder. This instrument has an acoustic transponder and release system and is designed primarily for multiple deployments as a fixed ocean bottom receiver for seismic refraction work.

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

INTERPOLATION OF UNIT VECTORS

Robert Parker and Charles R. Denham

In paleomagnetism and plate tectonics experimental studies give unit vectors representing the variation of a direction in space with time. (Both types of data are termed "poles" in their appropriate disciplines.) Normally the sampling in time is quite irregular because of the difficulty of finding datable material or continuous sequences. Therefore the need arises to interpolate these data, perhaps even to a continuous curve (e.g. a polar wander curve). This note gives a technique for constructing a smooth curve passing through the data with the following properties: the curve possesses continuous first and second derivatives (so that curvature is continuous); the curve does not depend on the choice of coordinate axes; it is easily constructed using widely available interpolation routines. The method can be extended to find curves with a higher order of smoothness, or to treat statistical error in the data.

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

THE OBLIQUE INTERSECTION OF THE MID-ATLANTIC RIDGE WITH CHARLIE-GIBBS TRANSFORM FAULT

Peter Lonsdale and Alexander Shor

The junction angle between the western Charlie-Gibbs transform fault and the spreading axis of the Mid-Atlantic Ridge diverges by 40° from the orthogonal intersection assumed in many studies of plate boundaries. This has been established by a surface-ship reconnaissance and by mapping of fault trends in a transponder-navigated deep-tow survey of the fracture valley 25 km from the intersection. One set of normal faults trends 325-330°, parallel to the obliquely spreading ridge axis, and another set trends 275°, parallel to the direction of relative plate motion. Although the near-bottom survey was in the theoretically inactive part of the fracture zone, beyond the transform fault section, there is evidence for recent motion on faults that cut the thick sediment fill of the fracture valley.

Oblique spreading of a ridge axis near a transform fault may result from distortion of the regional stress field by a strike-slip couple. Tension parallel to the long axis of the strike-slip strain ellipse, which is responsible for oblique normal faulting in transform valleys, causes oblique dike injection and oblique faulting in the axial rift valley. These effects extend further from transform fault intersections on slow-spreading ridges than on fast-spreading rises.

Supported by: [illegible]

A DEEP TOWED HYDROPHONE SEISMIC REFLECTION SURVEY AROUND IPOD SITES 417 AND 418

Graham M. Purdy, John I. Ewing, and George M. Bryan

Seismic reflection data collected using 0.66 litre (40 cm in) airgun and a single hydrophone towed within a few hundred metres of the sea floor defines the basement morphology close to IPOD drill sites 417A and 417D in the Western Central Atlantic Ocean. The high resolution provided by this technique, together with accurate navigation from acoustic transponder beacons, allows the basement hill into which these holes were drilled to be defined. Excellent agreement exists between the drilling results and these deep hydrophone reflection data.

Supported by: *Columbia University Subcontract # CU-WHOI 25906.*

MODELING THE OCEANIC MAGNETIC SOURCE LAYER

Hans Schouten and Charles R. Denham

The texture of an extrusive magnetic source layer and the variability of marine magnetic anomalies are studied as a function of two statistical parameters, λ and σ , that describe the temporal and spatial behavior of overlapping extrusive units that accumulated in an active spreading center, and subsequently, were transported outside. We use numerical simulations of an extrusive magnetic source layer and associated magnetic anomalies to combine the variability observed in sea floor spreading anomalies and Deep Sea Drilling Project cores with the FAMOUS observations. A simple two-parameter process of statistically controlled temporal (λ= 5-10 units/km spreading) and spatial (σ<2.5 km) emplacement of major extrusive units, adequately models most of the marine magnetic anomaly and *in situ* observations.

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

ON THE LIKELIHOOD OF MIXED POLARITY IN OCEANIC BASEMENT DRILL CORES

Charles R. Denham and Hans Schouten

The probability of striking mixed magnetic polarities in a deep oceanic crustal drill hole depends most heavily on the spreading rate, the width of the median valley where lavas accumulate and the width of the active spreading (stretching) zone. The temporal rate of extrusive activity has a relatively small effect. Numerical simulations and statistical estimates show that in s ow spreading rate crust, mixed polarity is very likely to occur both near to and far from the polarity boundaries which are inferred from the sea floor spreading magnetic anomalies.

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

TECTONICS OF THE WESTERN GULF OF OMAN

Robert S. White and David A. Ross

The Oman line, running northward from the Strait of Hormuz separates a continent-continent plate boundary to the northwest (Persian Gulf region) from an ocean-continent plate boundary to the southeast (Gulf of Oman region). Multi-channel seismic reflection profiles and gravity and magnetic data from the western portion of the Gulf of Oman obtained during a 1977 R/V *ATLANTIS II* cruise combined with single channel profiles taken from RRS *SHACKLETON* in 1975 further to the east provide adequate coverage of the area to describe the effects of the colliding plates in this region.

A large basement ridge detected north of the Musandam Peninsula, in the Strait of Hormuz is probably a subsurface continuation of the peninsula. Collision and underthrusting beneath Iran of the Arabian plate on which this ridge lies has caused many of the large earthquakes that have occurred in this region.

Convergence between the oceanic crust of the Arabian plate beneath the Gulf of Oman and the continental Eurasian plate beneath Iran to the north is accommodated by northward dipping subduction. A deformed sediment prism which forms the offshore Makran continental margin and which extends onto land in the Iranian Makran has accumulated above the descending plate. In the western part of the Gulf of Oman, continued convergence has brought the opposing continental margin of Oman into contact with the Makran continental margin. This is an example of the initial stages of a continent-continent type collision.

A model of imbricate thrusting is proposed to explain the development of the fold ridges and basins on the Makran continental margin and to show how the sediments are uplifted and incorporated into the accretionary prism.

Supported by: *NSF Grant OCE76-10417; and ONR Contract N00014-74-C-0262;NR 083-004.*

MULTI-BEAM SONAR DATA FROM THE ABYSSAL WESTERN PACIFIC AND PHILIPPINE BASIN

Morris F. Glenn and Charles D. Hollister

New multi-beam bathymetric data from the Philippine Sea and Northwest Pacific Basin reveal linear chains of small (less than 40 km^3) volcanic domes (Philippine) and cones (Pacific) rising 100 to 1000 m above the 6 km deep ocean floor. Some have well-developed collapse cal-

deras and spines. Their morphology suggests very recent formation in supposedly stable mid-plate regions and their occurrence in linear chains approximately parallel to plate motion suggests an origin through "mini-hot spots".

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

A GEOPHYSICAL SURVEY WITHIN THE MESOZOIC MAGNETIC ANOMALY SEQUENCE SOUTH OF BERMUDA

Graham M. Purdy and Kristin Rohr

This geophysical survey of an approximate one-degree square covers Mesozoic magnetic anomalies M0, M2 and M4. Bathymetry, magnetics, seismic reflection profiling and seismic refraction data are presented. The isochron trend of magnetic anomaly M4 time is 025°. An 11° clockwise change in trend seems to occur between anomalies M4 and M0 and is accompanied by the formation of a small offset right-lateral fracture zone. Two left-lateral fracture zones with offsets of 26-33 km also exist within the survey area. Seismic refraction data provide poor control on the shallow crustal structure but suggest the presence of significant lateral inhomogeneities within Layer 2.

Supported by: *International Phase of Ocean Drilling (IPOD) and ONR Contract N00014-74-C-0262;NR 083-004.*

A NEAR-BOTTOM TRAVERSE OF ROCKALL TROUGH: HYDROGRAPHIC AND GEOLOGIC INFERENCES

Peter Lonsdale and Charles D. Hollister

Two profiles with a deeply-towed instrument package provide a broken traverse of geologic and hydrographic data across the southern Rockall Trough. These near-bottom observations are supplemented with airgun profiles a CTD cast, and current meter data. Symmetric sand ripples at bathyal depths on both margins, which are superimposed on a field of sand waves on the slope of Rockall Bank, are attributed to bed load transport by tidal currents. Abyssal thermohaline currents are inferred from ripples, scour crescents and other indicators on more than 2000 stereo pairs of bottom photographs. In addition to the expected southerly currents on the western side of the trough, which is a passage for Norwegian Sea Overflow, there is evidence for fast, narrow and erosive currents of Labrador Sea Water and Northeast Atlantic Deep Water (NEADW) at the eastern boundary. The northeasterly NEADW current at the foot of the Irish Continental slope appears to be part of a cyclonic loop which brings silica-rich water into the trough, has built and is now eroding a narrow continental rise, and has transferred much terrigenous debris to the western side of the trough, for deposition along Feni Ridge. Maximum Late Pleistocene deposition on Feni Ridge has been on its northwest flank, beneath a weak reverse (northeasterly) current. On the southeastern flank of Feni Ridge local alternation of slow and fast sediment deposition (probably caused by topographically-induced local variations in current speed of the benthic boundary layer) has created 2 km-wavelength mud waves that migrate up the regional slope at less than 1 m/1000 years.

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

ACOUSTIC STRATIGRAPHY AND STRUCTURE OF THE OCEANIC CRUST

John I. Ewing and Robert Houtz

With the increase in resolution and the number of measurements, the early seismic model of the igneous crust composed of a 5 km/sec Layer 2 and a 6.8 km/sec Layer 3 evolved into one with at least two subdivisions for each layer. Recent work, in which arrival amplitudes have been given higher diagnostics priority than travel times in the data analysis, has suggested a further modification of the early model in which velocity gradients, with no distinct discontinuities, replace the layered model. Although the gradient model appears to be generally acceptable, there remains much to learn about the degree, scale and pattern of lateral variations in the velocity structure. Both seismic and drilling results indicate a substantial amount of inhomogeneity, particularly in the upper crust.

There is substantial evidence that several features of crustal structure are age-dependent, including:

(1) Topographic roughness of the upper crust diminishes with increasing age.

(2) Low velocity zones, possibly corresponding to magma chambers, are apparently confined to young lithosphere.

(3) The thickness of the low-velocity upper crust (Layer 2A) decreases and/or its wave velocity increases with increasing age. This effect may be due to cementation and lithification of rubble zones and to filling of fractures by mineralization, possibly associated with hydrothermal circulation in the crust.

(4) Total crustal thickness increases with increasing age.

(5) Because of greater sediment accumulation on older crust, and associated higher wave velocity in the basal sediments, the impedance discontinuity at the sediment-basement

interface tends to decrease with increasing crustal age; although the effect may be partially or totally counterbalanced by higher velocities in the upper part of the older crust.

(6) Reflections from the crust-mantle transition have been observed often in air-gun-sonobuoy profiles and in multi-channel reflection profiles in regions of old crust; much less frequently in young regions. It is not certain whether this is also an age-dependent effect or whether it is related to the difference in crustal topography and interference from diffracted arrivals.

Supported by: *ONR Contract with Lamont-Doherty Geological Observatory and NSF Grants with Lamont-Doherty Geological Observatory.*

AN ANALYSIS OF ISOSTASY IN THE WORLD'S OCEANS: PART 3 - ASEISMIC RIDGES

Robert S. Detrick and Anthony B. Watts

Fast Fourier transform cross spectral estimation techniques have been used to analize the relationship between gravity and bathymetry on 26 profiles across the Walvis and Ninetyeast Ridges. The resulting filters or transfer functions have been used to study the state of isostasy at these ridges. Transfer functions for the eastern Walvis Ridge and the Ninetyeast Ridge profiles can be explained best by an Airy-type thickening of the crust beneath these ridges. The crustal thicknesses required are in the range 15 to 30 km, in good agreement with available seismic refraction data. The transfer function for the western Walvis Ridge can be explained best by a flexure model in which the oceanic lithosphere is treated as a thin elastic plate overlying a weak fluid. The elastic plate thicknesses required are 5 to 8 km. These plate thicknesses are substantially less than those typically determined from flexural studies of loads on older crust, but are similar to estimates determined for sea floor topography at mid-ocean ridges. These observations are consistent with the formation of aseismic ridges near spreading centers on lithosphere that is young, thin and relatively weak. The differences in isostasy between the eastern and western Walvis Ridge are attributed to an off-axis shift relative to the South Atlantic spreading center of the "hot spot" forming the Walvis Ridge about 80 m.y.B.P. These observations suggest that the isostatic parameters determined for these aseismic ridges were "fixed" at the time of their formation at or near a spreading center and have not significantly changed through time.

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

MULTI-BEAM SONAR STUDY OF THE MID-ATLANTIC RIDGE RIFT VALLEY 36°-37°

Joseph D. Phillips and Henry S. Fleming

The SONARRAY array sonar echo-sounding system, of the U.S.Naval Oceanographic Office has been used to construct high resolution, five-fathom (9.2 m) contour interval bathymetric charts and profiles over the median and transform rift valleys of the FAMOUS area ($\simeq$ 4200 km^2). Only abour three days of ship time were required to obtain the bathymetry data. The high ship's speed and resolution of array-type sonar systems results from the fact that a wide swath perpendicular to the ship's track is continually insonified by many narrow beams rather than by a single beam directly beneath the ship. Beam forming and positioning is accomplished by electronic simulation of attitude information provided by the ship's inertial navigation system. Analysis of the SONARRAY-derived charts and profiles has revealed several new distinctive topographic features characteristic of the oceanic ridge axis here. Specifically: low relief ($\simeq$ 100 m elevation) linear hills form the median rift valley inner floor; narrow ($\simeq$ 1 km) flat-topped terraces and benches with outward facing antithetic scraps characterize the median rift walls; quasi-circular ($\simeq$ 10 km dia.) nodal basins are found at the intersection of the transform faults with the median rift valley; and narrow ($\simeq$ 2 km) trough and ridge lineaments found along the transform rift valley floors probably mark the site of recent horizontal faulting.

Supported by: *NSF Grant DES 73-06421.*

GEOLOGICAL AND GEOPHYSICAL INVESTIGATION OF THE MID-CAYMAN RISE SPREADING CENTER: INITIAL RESULTS AND OBSERVATIONS

Robert D. Ballard, Wilfred B. Bryan, Henry J.B.Dick, Kenneth O. Emery, Geoffrey Thompson, Elazar Uchupi, *et al.*

The intensive survey of the Mid-Cayman Rise spreading centermade possible by the use of sophisticated marine geological and geophysical tools has provided a wealth of data enabling us to define some of the tectonic and petrologic complexities of this accreting plate boundary. Remote sampling by dredging has provided a suite of basaltic and plutonic rocks which presumably comprise layers two and three of the oceanic crust of the Cayman Trough. Direct sampling by *ALVIN* has given us an opportunity to observe and collect *in situ* rocks presumed to form the foundation of the oceanic crust. Topographic features within the zone of recent volcanic activity have been observed with the use of *ANGUS* and *TRIESTE II*. The compilation of a bathymetric map with the aid of *SEABEAM* has allowed us

to delineate regional topographic elements and to constrain geographically the photographic, dredge and dive data.

Several questions of first-order importance remain to be answered. The predominance of plutonic rocks with typical tholeiitic affinities on both sides of the rift valley over a distance of 60 km suggests that we have sampled seismic Layer 3 rather than an isolated shallow level intrusion. In addition, the recovery by *ALVIN* of a small amount of basalt from talus slopes and the observation of a series of small scarps of pillow basalt high on the west wall (Dive Area #2) imply that extrusive and shallow intrusive rocks cap the plutonic complex at the top of the rift valley escarpments.The disproportinate lack of extrusive and shallow intrusive rocks in such closely sampled terrain is therefore difficult to explain in terms of current models of accretionary processes. It is possible that the presence of cold bounding lithosphere to the N and S of the spreading center along the Oriente and Swan transform faults exerts a profound influence on accreting plate boundary processes along this short ridge segment and results in a thin basaltic carapace; *in situ* sampling of gabbro to within 200 m of the top of the rift valley escarpments would suggest, from this model, that the extrusive carapace is no thicker than 200 m. Alternatively, it may be necessary to invoke structural or tectonic removal of the crust comprising the extrusive and shallow intrusive lid in the Cayman area.

Future work on the extensive and diverse collection of data will attempt to answer these first-order questions. The wealth of available material also allows us to address fine-scale problems: the effects of primary igneous and secondary alteration processes on the chemistry of the dredged basalts and the well-constrained *ALVIN* collection of plutonic rocks; the structure of the oceanic crust as inferred from the physical properties (velocity as well as magnetics) of samples that have been collected *in situ*; and the extent of deep-level deformation as indicated by micro- and macrostructure of plutonic samples.

Supported by: *Deep Sea Drilling Project.*

THE NORTH ATLANTIC RIDGE: OBSERVATIONAL EVIDENCE FOR ITS GENERATION AND AGING

James R. Heirtzler

During the period 1963-69 a beautifully simplistic picture of seafloor spreading and global tectonics was developed. One of the most attractive aspects of the seafloor spreading theory is how the seafloor is created at the mid-ocean ridges, and there gets magnetized with a polarity determined by the direction of the earth's ambient field at the time.

It was realized at that time that this simplistic theory would require elaboration and possibly modification as our knowledge increased. During the last ten years, there have been three major types of studies of the ocean crust that bear on the theory of seafloor spreading:

1. Geological and geophysical studies of the axes of the ridges with precisely located instruments and with manned submersibles, especially on the Mid-Atlantic Ridge south of the Azores (Projects FAMOUS and AMAR), in the Cayman Trough of the Caribbean, in the Galapagos Rift, and near the Tamayo Fracture Zone of the East Pacific Rise. These studies have revised our simple ideas about how crust is emplaced and provided insight into its episodic nature.

2. Deep sea drilling at a number of sites. In the North Atlantic, holes were drilled from near the ridge axis to sites in very old crust. As of this time, 21 Atlantic sites have penetrated more than 20 m into the basaltic basement on Legs 37, 38, 45, 46, 49, 51, 52, and 53 (Figure 1). These sites range in age from 1.6 to 110 million years, and shallower penetration was made in crust of about 150 million years of age. Recovered samples have indicated how the upper part of the oceanic basement changes with age, and provided help in the interpretation of geophysical profiles taken by research vessels operating on the ocean surface and using remote sensing instruments.

3. Geophysical studies between the mid-ocean ridge axial region and the edges of the oceans. Significant achievements include the discovery that the uppermost seismic layer (Layer 2) can be subdivided into Layers 2A, 2B, and 2C and that these subdivisions change in thickness in a generally systematic way with age. Also, the detailed mapping of magnetic anomalies, especially in the North Atlantic, has permitted an understanding of how the initial opening of the ocean took place, of how spreading rates have changed with time, and how fracture zones have altered their positions as the ocean opened.

While all of the investigations have proved fresh observational data, this data is not always in agreement with the simple seafloor spreading theory. For example, it is not clear how many of the observations are related to spreading rate. It is not clear how many of the major rises and non-mid-ocean (aseimic) ridges are to be accommodated with the age depth cruve or why many of the seamounts have subsided as they have and how, or if seamount chains are related to isolated upwellings (hot spots) of mantle material. The location of the magnetic anomaly source layer has not been clearly identified by

drilling. The details of the oceanic continental crust interface at passive margins - like the margins of the Atlantic - have not yet been explored in any detail. Even in mid-plate regions the question of regional variability is not appreciated because of the thick sediment cover.

It is not possible to discuss here all of the recent studies.Most have been covered in comprehensive papers of their own. It may be most instructive here to identify observations that will probably have the most far-reaching effects, or to identify new sets of observations that are mutually supporting and that identify new phenomena.

Supported by: *Joint Oceanographic Institutions, Inc.*

SEISMIC REFRACTION AND REFLECTION STUDIES IN THE TIMOR-ARU TROUGH SYSTEM AND AUSTRALIAN CONTINENTAL SHELF

Randell S. Jacobson, George G. Shor, Jr., R. M. Kieckhefer and Graham M. Purdy

Seismic refraction and reflection profiles were carried out on the continental shelf and slope north of Australia and in the Timor-Tanimbar-Aru Trough system of the Banda Sea. This trough system, not deeper than 3.6 km, is the eastern extension of the Java Trench. Morphologically, the area is very similar to other circum-Pacific subduction zones, although continental crust, rather than oceanic crust, is being thrust under a series of emergent nonvolcanic imbricated islands.The refraction results reveal a close similarity between the crust underlying the continental shelf and that under the trough system. Typical continental crustal thicknesses (up to 40 km) and velocities were observed. Reflection profiles reveal that the continental slope was formed by predominantly normal faulting and active subsidence, presumably related to the downwarping of the continental shelf into the subduction zone. A tectonic front at the landward (northern) wall of the trough system compressionally deforms unlithified sediments. Uplifting of small crustal blocks into the inbricated island trend is also apparent. The data strongly support the idea that the Timor-Tanimbar-Aru Trough system is the surface of a subduction zone.

Supported by: *NSF Grants OCE75-19150 and OCE75-19387; and ONR Contract N00014-75-C-0749,*

PALEONTOLOGY/ SEDIMENTOLOGY

SALT DIFFUSION IN EASTERN MEDITERRANEAN SEA SEDIMENTS

Henry Elderfield and Colin P. Summerhayes

The Nile Submarine Fan, in the south-eastern Mediterranean, overlies Messinian evaporites from which vertical diffusion of salt would be expected to lead to enrichment in the salinities of sediment pore waters. Such enrichment is observed east and west of the fan, but the only part of the fan showing enhanced salinities is at the north of the Levant Platform where there are abundant salt diapirs. No enrichment was observed on the Nile Cone, probably because thick turbidite sequences prevent significant vertical transport of salt.

Published in: *Deep Sea Research, 25: 837-841.*

LATE PLEISTOCENE AND HOLOCENE SEDIMENTATION IN THE PERSIAN GULF - GULF OF OMAN

Peter Stoffers and David A. Ross

Studies of 13 piston and gravity cores from the Persian Gulf and Gulf of Oman, collected during a 1977 *ATLANTIS II* cruise, showed that distinct and correlative sedimentary units can usually be distinguished in the Late Pleistocene and Holocene sediments. The units from the Persian Gulf are:

Unit 1 - olive-grey marl of variable thickness (50 to > 100 cm) that was deposited within the last 5,000 or 6,000 years B.P. The sediments are very silty and contain abundant biogenic constituents; carbonate content is about 55%. The most characteristic and diagnostic mineral of this unit is high magnesian calcite.

Unit 2 - light greenish-grey carbonate mud with occasional intercalated lithified carbonate layers. The mud is basically composed of clay-sized aragonite needles, and carbonate content is > 70%. In the coarser size fraction oolites and pellets, often of black color, are abundant. This unit is commonly about 10 to 100 cm thick and was deposited between 6,000 to 12,000 years B.P.

Unit 3 - greyish-brown detrital silt deposited between ~12,000 and at least 30,000 years B.P. Carbonate content ranges between 35 and 59%. Calcite and dolomite, including Ca-dolomite, are the main constituents. In the lower part of this unit the sediments are highly compacted (water content <20%).

These sedimentary units are related to the major changes in the environmental condi-

tions of the Persian Gulf. Unit 3 was deposited when the Persian Gulf was essentially a large river valley crossed by the ancient Shatt-al-Arab River which discharged directly into the Gulf of Oman. Unit 2 was deposited in a period of rising sea level and the establishment of marine conditions within the Persian Gulf. Unit 1 has been deposited since the time that sea level has essentially reached its present level.

In the Gulf of Oman terrigenous sediments dominate and the main constituents are chlorite and illite. Carbonate content decreases toward the central part of the basin to less than 20% and consists of calcite with little dolomite. The presence of aragonitic material in certain sedimentary intervals clearly demonstrates transport of shallow water sediments by turbidity currents into the deeper basin. Sedimentation rates for the central basin of the Gulf of Oman are in the order of ∿50 cm/1,000 years.

Supported by: *NSF Grant OCE76-10417.*

THE LATITUDINAL AND BATHYMETRIC RANGES OF LIVING AND FOSSIL Mesodesma arctatum *(BIVALVIA) WITH NOTES ON HABITS AND HABITAT REQUIREMENTS*

Arthur S. Merrill, John D. Davis and Kenneth O. Emery

Living adult *Mesodesma arctatum* range from Belle Isle Strait between Labrador and Newfoundland south to the eastern shore of Long Island, New York. A companion species, *Mesodesma deauratum*, is restricted to the St. Lawrence Estuary and the western portion of the north shore of the Gulf of St.Lawrence. Both species are intertidal residents generally restricted to well-sorted sand and gravel in shal ow water particularly adjacent to the mouths of streams and tidal inlets. Fossils of *M.arctatum* range from Hare Island, western Greenland, to Cape Hattaras, NC (and possibly even to Beaufort Inlet, NC). Fossils are common on the middle Atlantic shelf to a depth of 355 m, and they even have been transported beyond the shelf by strong currents to the floor of the Hudson Canyon at depths of at least 3,470 m. Radiocarbon dating indicates that many of these fossils now found at latitudes and depths beyond the present range lived during the Holocene Stage of the Quaternary.

Supported by: *Henry Bryant Bigelow Oceanographer Chair.*

LOWER TERTIARY BIOSTRATIGRAPHY AND TECTONICS OF NORTHEASTERN LIBYA

Frank T. Barr and William A. Berggren

Foraminifera from the Apollonia Limestone are described from the coastal area between Susah and Darnah in northeastern Cyrenaica. These well-preserved faunas provide a detailed zonation of this stratigraphic succession. Paleoecological information suggests a progressive shallowing of the Eocene seas in this area, from bathyal depths in the Ypresian to neritic conditions during the Lutetian.

These data have been incorporated with stratigraphic information from other parts of Jabal al Akhdar to establish a generalized reconstruction of the early tectonic history of northern Cyrenaica. Evidence suggests that a major tectonic event commences with weak movements during the Late Cretaceous (late Campanian or early Maastrichtian) reaching its maximum intensity at the end of Paleocene time when much of the Jabal was uplifted, folded and severely eroded. Orogenic movements, although less severe, probably continued into the Early Eocene (Ypresian). A transgression commenced during the Ypresian, with seas advancing into the basinal areas from the north and slowly onlapping the steep flanks of the folded highlands. The entire Jabal al Akhdar area was finally again inundated by marine seas during the Middle Eocene (Lutetian) which represented a period of tectonic quiescence

Supported by: *Grants from various Oil companies and an NSF Grant OCE76-21274.*

RELATIONSHIP BETWEEN THE DISSOLUTION RATES AND THE CHEMISTRY OF THE DEEP OCEAN WATER IN THE NORTH ATLANTIC

Taro Takahashi and Susumu Honjo

The results of recent calcite dissolution experiments in the North Atlantic Ocean by Honjo and Erez support the calcite solubility value obtained by Ingle *et al.* over that by Berner, and are consistent with the critical carbonate value for calcite dissolution proposed by Broecker and Takahashi. In order to compare the calcite dissolution rates obtained by Honjo and Erez in the deep ocean with those obtained in the laboratory by Gerner and Morse and Morse, an equation relating the calcite dissolution rate with $CO_3^=$ ions in solution has been derived and fitted to the laboratory data. The rate of calcite dissolution increases rapidly with decreasing $CO_3^=$ ion concentration in seawater as an exponential function of $(CO_3^=)^{n/2}$.

where n ranges between 6 and 14 depending upon the origin of the calcite crystals (coccolith foraminifera test, Iceland spar etc.). Assuming that this relationship is valid in the high pressure and low temperature conditions of the deep ocean, the rate of calcite dissolution in the North Atlantic Ocean has been computed using the $CO_3^=$ data obtained at the Honjo-Erez experimental site. The calculated values are in agreement with those obtained by the Honjo-Erez *in situ* experiments. The relationship between the "planktonic foraminifera" (or "foram") and "sedimentary" lysocline and the calcite dissolution rate in the North Atlantic is discussed.

Supported by: *ONR Contract N00014-75-C-0210 and NSF Grant IDOE OCE76-82035.*

PALEOGENE BENTHONIC FORAMINIFERAL BIOSTRATIGRAPHY AND BATHYMETRY OF THE CENTRAL COAST RANGES OF CALIFORNIA

William A. Berggren and Jane Aubert

Paleogene benthonic (and to a lesser extent, planktonic) foraminiferal assemblages have been examined from the stratotype Lodo Formation (late Paleocene-early Eocene, Zones P4-P9) (Fresno County), the Devils Den Aqueduct section (early-middle Eocene, Zones P8-?P10) (Kern County), and the Locatelii (late Paleocene) and Butano (early Eocene) formations of the Santa Cruz Mountains, California.

Benthonic foraminitera indicate that the stratotype Lodo Formation was deposited during a single sedimentary cycle (lasting about 10 my) at depths ranging from outer neritic (>200 m) near the base and in the upper half to mid-upper bathyal (~600 m) in the lower half. The Gredal Shale Member of the Kreyenhagen Formation in the Devils Den Aqueduct Section contains a rich planktonic foraminiferal fauna throughout and no evidence in the upper part of the neritic fauna present in the upper part of the stratotype Lodo Formation. Middle bathyal depths (>600 m) are suggested for the lower part, upper bathyal depths (~600 m) for the upper part.

The marked shallowing which occurs in these sections over the late P8-early P9 interval is denoted by the local disappearance and/or sporadic occurrence of bathyal taxa (*i.al. Nuttallides truempyi)* with more extensive stratigraphic ranges elsewhere and coincides closely with a major eustatic sea-level fall recently delineated in seismic stratigraphy.

The faunal assemblates from the Santa Cruz Mountain sections are predominantly agglutinated (with minor calcareous benthonic and planktonic elements) and are characteristic of flysch deposits formed at the distal margins of turbidite fan(s) in water depths of 1-2 km. Whereas the calcareous benthonic assemblages of the Lodo and Gredal formations contain numerous cosmopolitan elements, the agglutinated flysch faunas of these units and the Santa Cruz Mountains appear to be less cosmopolitan (i.e. they do not appear to be closely related to Paleogene flysch faunas of the Carpathian Mountains of the North Atlantic.

To be published in: *U.S.Geol.Surv.Prof. Papers.*

Supported by: *Various Oil Companies.*

QUANTITATIVE PALEOBATHYMETRY AND PALEOECOLOGY OF THE LATE PLIOCENE-EARLY PLEISTOCENE FORAMINIFERA OF LE CASTELLA (CALABRIA, ITALY)

Mary L. Bremer, Madeleine Briskin, and William A. Berggren

The paleobathymetry and paleoecology of the Pliocene/Pleistocene boundary stratotype section at Le Castella (Calabria, Italy) has been derived from a study of benthonic and planktonic foraminifera.

A Q-mode principal component analysis simplified the benthonic census data to a few assemblages which were subsequently compared to the present-day eastern Mediterranean surface sediment benthonic population described by Parker (1958). The comparison indicates that the Le Castella benthonic foraminifera are similar to those occurring between 130-700 m in the Mediterranean today - a range occupied by the Intermediate Water Mass.

Benthonic foraminiferal principal component II summarizes the greatest dimension of variation in the Le Castella faunal census data. The taxa *Cassidulina laevigata, Uvigerina peregrina, Bulimina costata, B. aculeata + marginata* and *Hyalinea baltica* dominate one end-member of principal component II; *Cibicidoides floridanus* dominates the other.

A change in the relative abundance of these two assemblages occurs just above the Pliocene/Pleistocene boundary (marker-bed). In the Pliocene section the fauna is characterized by frequent fluctuations between the *Cassidulina laevigata-Uvigerina peregrina* assemblage and the *Cibicidoides floridanus* assemblage; in the Pleistocene unit, the *Cassidulina laevigata-Uvigerina peregrina* assemblage dominates. The only reported recent occurrence of *C. floridanus* with abundances similar to those of Le Castella is in the Gulf of Mexico.

Relatively high percentages of warm-water planktonic foraminifera are associated whti the *Cassidulina larvigata-Uvigerina peregrina* assemblage whereas relatively low percentages are associated with the *Cibicidoides floridanus*

assemblage. The integrated planktonic and benthonic foraminiferal evidence delineates a record of two climatic regimes in the stratotype. A series of frequent climatic fluctuations, alternating between a characteristically Mediterranean climate and one comparable to the Gulf of Mexico today, characterizes the Late Pliocene. Pleistocene regime is typified by a relatively constant climatic regime comparable to the Recent.

Supported by: *Penrose Bequest Grant 2134-76 and Various Oil Companies.*

SEDIMENTATION IN THE FRASER RIVER AND ITS ESTUARY, SOUTHWESTERN BRITISH COLUMBIA (CANADA)

John D. Milliman

The Fraser River, largest river (in terms of both water and sediment discharge) reaching the west coast of Canada, is a sand-dominated river in which most sediment transport occurs during freshet in late spring and early summer. More than half the sediment discharged during this two-to-three month period is sand. Throughout the rest of the year, the river is characterized by decreased flow and low suspended sediment concentrations (primarily silt and clay); net offshore transport during these months is slight, and near-bottom transport appears to be upstream.

The dominance of sand transport in the Fraser results in an estuarine depositional regime quite different from most mud-dominated rivers and estuaries. Although most sediment in the upper and middle sections of the river is carried in suspension, about 40 percent of the sand (20 percent of the total load) settles from suspension in the upper estuary. Field measurements show that most of the remaining freshet sand settles prior to reaching the lower estuary.

In a natural situation, much of the river sand probably would continue moving seaward as bed load, as suggested by the prevalence of migrating sand waves in the middle estuary during freshet. Longshore drift of this sand has built tidal flats that now dominate the nearshore environment. Dredging river channels and construction of jetties across shoal areas, however, probably have interrupted both offshore and longshore transport. Moreover, jetties at the river mouth channelize flow across the narrow shelf, resulting in sand resuspension and subsequent offshore transport in the less dense surface waters.

Supported by: *U.S. Geological Survey Contract #16515.*

LATE CENOZOIC SEDIMENTATION AND EROSION ON THE RIO GRANDE RISE

David A. Johnson and Christopher S. Peters

The Rio Grande Rise, an aseismic ridge in the southwestern Atlantic, is capped by a thick sequence (up to ∿1 km) of pelagic carbonate 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 (∿25 km^2) on the north flank allow an interpretation of the depositional environment on the Rio Grande Rise during the late Cenozoic, and place constraints on the origin of the series of erosional canyons nearby. Initial development of the canyon system probably coincided with erosion of the shallower portions of the rise near sea level during the late Cretaceous. As the Rise subsided during the Paleogene and early Neogene, pelagic carbonates accumulated on bedding surfaces which strike east-west and dip greatly (∿1°) northward. Portions of the rise remained at or very near sea level until as recently as the early Oligocene. Subsidence of the rise during the Cenozoic has been at rates equal to or greater than the mean subsidence rates for "normal" oceanic crust of the same age.

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 ∿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 net accumulation 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 Ter-

tiary when portions of the Rise were at or above sea level; (b) Deepening of the canyons during the Tertiary via a sequence of erosional episodes alternating with relatively quiescent depositional intervals; and (c) Cessation of major canyon cutting in the late Pleistocene (~370,000 y.B.P.).

Canyon cutting was most intense between the latest Miocene and late Pleistocene, perhaps as a consequence of the re-structuring of circulation systems at shallow and intermediate depths in response to the growth of the Antarctic ice cap and the northward penetration of Antarctic Intermediate Water.

Supported by: *NSF Grant OCE74-01744 and ONR Contract N00014-74-C-0262;NR 083-004.*

LATE NEOGENE CALCAREOUS PLANKTON BIOCHRONOLOGY OF THE RIO GRANDE RISE (SOUTH ATLANTIC OCEAN)

Bilal U. Haq and William A. Berggren

Late Miocene-Pliocene calcareous nannoplankton biostratigraphy of eight piston cores from the Rio Grande Rise is presented and ranges of selected nannofossil taxa are integrated with ranges of selected planktonic foraminifera to obtain an accurate biochronology for this interval. Four of the nannofossil biostratigraphic zonal concepts are modified and both nannofossil and planktonic foraminiferal zonations are calibrated against paleomagnetic stratigraphy and absolute chronology. Estimates of the ages of fourteen nannofossil and twenty planktonic foraminiferal datum levels are presented; of these five (and possibly six) nanno fossil datums are considered reliable for interoceanic correlations of late Neogene (excluding Pleistocene) tropical-temperate areas.

Light micrographs of almost all nannofossil taxa of the late Neogene are presented in five plates. One new species (*Sphenolithus grande*), one new subspecies (*Discoaster browweri bipartitus*) and four new combinations are proposed.

Published in: *Journal of Paleontology, November, 1978.*

Supported by: *NSF Grants OCE76-21274, OCE77-82149 and OCE74-01744.*

EARLY CENOZOIC CALCAREOUS NANNOPLANKTON BIOSTRATIGRAPHY AND PALEOBIOGEOGRAPHY OF NORTH AFRICA AND THE MIDDLE EAST AND TRANS-TETHYAN CORRELATIONS

Bilal U. Haq and Marie-Pierre Aubry

In the Early Cenozoic, North Africa and the Middle East formed important parts of the Tethyan link between the Atlantic Ocean on one side and the western Pacific Ocean on the other. The epicontinental marine Paleocene-Eocene sections of this region are indispensible in the understanding of calcareous plankton biogeographic patterns on both regional (Tethyan) and world-wide basis. In this paper we present calcareous nannoplankton biostratigraphy of the Paleocene-Eocene from Wadi al Atrun and Pyramid Peak sections in northern Cyrenaica, N.E.Libya; Djebel Cherahil, Djebel Bou Dabbous and El-Kef sections in Tunisia; Jebel-um-Rejam section in Jordan; Cherkessk and Essentuki sections in the Caucasus Mountains, U.S.S.R., and the Jebel Jenine sections in Lebanon. Correlations of Paleocene-Eocene strata in the trans-Tethyan region (North Africa, including Egypt, and the Middle East, including Iran and Pakistan) based on nannofossil and planktonic foraminiferal biostratigraphy, are suggested.

A comparison of the Paleocene-Early Eocene biogeographic patterns of the Atlantic Ocean with well-preserved assemblages of the trans-Tethyan region show that the constituents of the open-ocean were essentially similar to those found in the Tethys seaway, with temporal differences in the relative dominance of some taxa in the late Paleocene. One relatively cold assemblage (*Prinsius martinii*) persists for a longer time in the Central Tethys, than it does in similar latitudes of the Atlantic. The DSDP sites in the Bay of Biscay show a nannoflora that is essentially Tethyan in character.

Light micrographs of some less well-known taxa and scanning electron micrographs of well-preserved assemblages are illustrated. Three new species are described: *Fasciculithus aubertae, F. stonehengeni* and *Heliolithus floris.*

Supported by: *NSF Grant OCE76-21274.*

LATE PLIOCENE-PLEISTOCENE CALCAREOUS PLANKTON STRATIGRAPHY OF THE RIO GRANDE RISE

Christopher S. Peters

Five piston cores form the Rio Grande Rise, recovered on *CHAIN* 1125 Leg 6, contain a continuous stratigraphic sequence of calcareous plankton microfossils from 3.3 Ma to the present. This sequence extends upward the Late Miocene to Late Pliocene calcareous

plankton biochronology proposed by Berggren (1977b) and Haq and Berggren (1978).

First appearance datums (FAD) and last appearance datums (LAD) of eleven species of calcareous nannoplankton and planktonic foraminifera form the basis for a biostratigraphic framework in these sediments. Using previously established datum levels, the resulting Pliocene-Pleistocene sequences for all five cores were compared to currently proposed biochronologies, notably that of Haq *et al.* (1977). The Rio Grande Rise data fit the Haq *et al.*,(1977) biochronology well, except for the *Globigerinoides obliquus* LAD, which is placed here at 1.8 Ma, instead of at 1.6 Ma as they suggested.

Age-depth plots were constructed for the various datum levels and sedimentation rates were calculated for four different intervals of the cores, using selected datum levels as control points. A constant sedimentation rate was assumed between two successive control points, the basis for which has been verified for at least the Pleistocene sediments, where the *G. menardii* zone boundaries in core 85 approximate a straight line fit.

On the basis of these graphs, a major change in sedimentation is inferred at approximately 2.9 Ma. Sedimentation rates appear to have decreased by one-quarter to one-eighth (from ∿.8 to ∿.1 or .2 cm/10^3 yr) for the time period following this change (2.9 to 2.25 Ma). This may correspond to a major change in Antarctic Bottom Water flow through the Vema Channel. Sedimentation rates remained low (∿.1 cm/10^3 yr) in the latest Pliocene (2.25 to 1.8 Ma) and increased about two-fold (.20 to .25 cm/10^3 yr) in the Pleistocene. These results may not reflect regional patterns of sedimentation, as other studies have shown that sedimentation on the Rio Grande Rise is highly variable and localized.

Supported by:*NSF Grant OCE74-1744.*

THE SEDIMENTS OF THE ARGO ABYSSAL PLAIN AND ADJACENT AREAS, NORTHEAST INDIAN OCEAN

Peter J. Cook, John J. Veevers, James R. Heirtzler, and Peter J. Cameron

A series of geophysical traverses by the *ATLANTIS II* across the Argo Abyssal Plain, together with coring at a number of selected localities has provided new information on sedimentary and tectonic processes in this region of the northeast Indian Ocean. Isopach maps prepared from the seismic profiles show that sediment thicknesses crudely parallel the bathymetry. The presence of some diapirs in the Argo Abyssal Plain was indicated. It was not possible to say from the present program whether the probable diapirs are salt or mud-cored. A diverse group of cores were obtained from a variety of sites including siliceous clays from below the CCD, calcareous oozes from above the CCD, calcareous clays (showing evidence of abundant sulphate reduction) from a fore-arc basin site, and manganese nodules from an abyssal site. In addition, hyaloclastites from the Joey Rise area (north of the Exmouth Plateau), suggest that the Joey Rise, and possibly also the Roo Rise, are underlain by basaltic material. A sample of basalt was also recovered from the outer part of the Exmouth Plateau.

Published in: *BMR Journal of Australian Geology and Geophysics, 3:113-124, 1978.*

Supported by: *NSF Grant OCE75-20674.*

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 (∿100 km) topographic gap near 09°S, 52°E which restricts the flow of the deep western boundary current (DWBC) from the Mascarene Basin into the Somali Basin in the western Indian Ocean. Seismic reflection profiles, 3.5 kHz echograms, nephelometer profiles, hydrographic data, bottom photographs, and piston cores show that deposition of sediment within the passage below ∿3800 m is controlled by relatively strong flow of the DWBC. The channel axes contain highly reflective, horizontally-stratified deposits whose acoustic character indicates erosion and/or non-deposition. Thick (up to 0.5 sec), acoustically transparent drift deposits and sediment waves are widespread across the lower flanks of the adjacent ridges and along the channel margins. Current flow appears to be strongest in the channel axes, and becomes progressively weaker toward the channel margins. The regional distribution of drift deposits (depositional regime) and channel deposits (erosion or non-depositional regime) indicates a western intensification of the DWBC flow within the passage. Moreover, the presence of steep, asymmetrical ripples, strong scour, and highest light-scattering values in the Western Channel suggest that the DWBC flow may be most intense within the Western Channel, even though this channel has the shallowest sill depth of any of the channels in the passage. Drift deposits overlie channel deposits at several locations in eastern channels, and manganese pavements occur at shallow subbottom depths east of the present-day DWBC axis, suggesting that the DWBC flow may have been broader and/or more intense during the geological past.

Large fields of well-developed abyssal sediment waves, with heights of tens of meters and wavelengths up to a few kilometers, flank the Western Channel. These bedforms are best developed only at the channel margins, and only within a narrow depth interval which corresponds approximately with that of the near-bottom mixed layer (~3800 to 4000 meters). The lithology, micro-relief, sub-bottom stratification, and regional distribution of the sediment waves suggest that they are constructional bedforms produced by deposition from the DWBC within the Western Channel. Reflection profiles indicate that net accumulation rates increase systematically outward from the channel axis. The sediment waves may thus reflect, and perhaps may be a consequence of, a strong horizontal velocity shear at the channel margins. The presence of well-formed sediment waves in biogenic ooze suggests that proximity to large supplies of terrigenous sediment (i.e., turbidity current channels) may not necessarily be required for the generation of wave-like bedforms on this scale.

Supported by: *NSF Grant OCE76-20154.*

SEDIMENTARY FABRIC: A TOOL TO DELINEATE A HIGH-VELOCITY ZONE WITHIN A DEEP WESTERN INDIAN OCEAN BOTTOM-CURRENT

B. Ellwood Brooks, Michael T. Ledbetter and David A. Johnson

Previous work on deep-sea sediments underlying high velocity deep western boundary currents (DWBC) indicates that changes in sediment fabric as determined by the standarized anisotropy of magnetic susceptibility (AMS) parameter F_s may be due to fluctuations in near-bottom current velocity. The AMS parameter is sensitive to long-axis alignment of magnetic grains and when combined with particle size analyses of the fine-fraction of the same sediment, provides a method to recognize variations in bottom-current velocity.

In summary, the sedimentary fabric as determined by AMS and silt mean measurements of surface sediment samples suggests that the northward-flowing DWBC is flowing fastest in the deeper portions of the passage. Low values of F_s and silt particle size at ~4100 meters on both margins of the passage may represent the top of the high-velocity portion of the DWBC.

Supported by: *NSF Grants OCE76-20154 and OCE76-21822.*

MARINE RESOURCES

A REVIEW OF [illegible] AND LIMNOLOGY IN ISRAEL

Kenneth O. Emery

Oceanography and limnology in Israel has had a long history of development: several thousand years of general observations mostly not recorded, a century or two of foreign expeditions, and thirty years of Israeli national scientific growth. The groundwork for further expansion of this growth has been laid for the seas and lakes of the region as well as farther afield.

Supported by: *Henry Bryant Bigelow Oceanographer Chair.*

EXPORTS OF NATIONS

Kenneth O. Emery and Rufus D. Catchings

The ratio of dollar value of exports of manufactured goods to dollar value of raw materials serves as an indicator of industrial and technological levels of different nations. When compared with gross national products, the ratio reveals rather clear differences getween nations that are generally known for manufacturing, for geological (non-renewable) raw materials, and for biological (renewable) raw materials.

Supported by: *Henry Bryant Bigelow Oceanographer Chair.*

MARINE MINERAL RESOURCES AND UNIFORMITARIANISM

Kenneth O. Emery

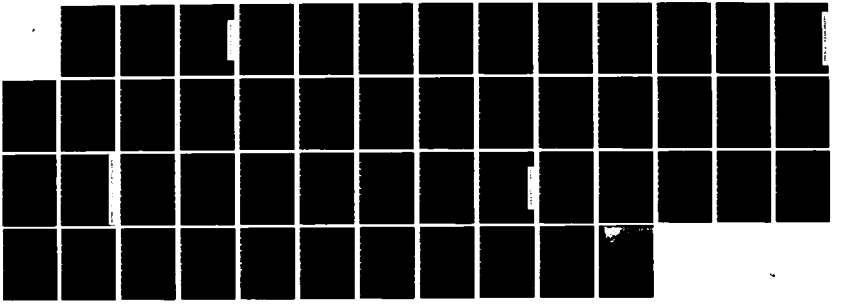
Fossil fuels and other mineral deposits can be considered examples of the general principles of uniformitarianism, because they have been formed during long geological time by geological processes that are more or less understood. In contrast, man's mining of the deposits has undergone a logarithmic increase in rate since the Industrial Revolution, in keeping also with the logarithmic increase in world population; this is considered an example of catastrophism - both for the mineral deposits and for mankind. Effects of mineral shortages from the land and ocean floor are being felt both by industrially advanced and underdeveloped countries, but their political remedies are almost diametrically opposite.

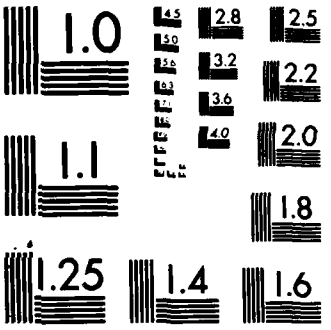
Published in: [illegible]

Supported by: [illegible]

AD-A140 593 ABSTRACTS OF PAPERS SUBMITTED IN 1978 FOR PUBLICATION (U)WWOODS HOLE OCAANOGRAPHIC INSTITUTION MA M C THAYER 1978 WHOI-REF-79-37 2/2

UNCLASSIFIED F/G 5/2 NL





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

RESOURCES OF THE DEEP SEA OTHER THAN MANGANESE NODULES

David A. Ross

During the Law of the Sea (LOS) negotiations, discussion of deep sea resources has centered essentially on manganese nodules. This is an appropriate decision since manganese nodules, and their contained elements, have the most immediate potential as a marine mineral resource in the region outside of pending national jurisdiction. The objective of this paper is to describe some of the "other possible resources" of the deep sea - but I wish to emphasize that few of these "other possible resources" are economically meaningful at this time and most may never be.

Before starting, some definitions are appropriate. A resource in a simple sense means a supply of something be it food, minerals or water. Resources such as food or forests are considered to be renewable resources since their supply can be replenished by photosynthesis or other processes. Mineral deposits, on the other hand, are generally considered to be nonrenewable resources since their supply decreases as the material is used. Resources also can be subdivided on the basis of economics. In general, the term resources is applied to a supply that can be worked or produced at a price somewhat higher than presently prevailing. A marginal or paramarginal resource is one that is recoverable at one to one-and-a-half times the prevailing price whereas a submarginal resource requires higher costs. A reserve is a known deposit that can be developed under present technological and economic conditions. These terms are obviously not very precise and what is at one day a resource can often become a reserve the next. This, as we shall see, is not, however, generally the case for deep-sea mineral resources.

One other important point is necessary as an introduction. That is the generally voiced concern that we - the world - are rapidly running out of mineral resources. The earth itself, as well as sea water, contains an immense and essentially inexhaustible supple of minerals. An example often quoted is that just one cubic kilometer of average crustal rock contains 200,000,000 tons of aluminum; 100,000,000 tons of iron; 800,000 tons of zinc, etc. Sea water, likewise contains vast amounts of different elements such as over three billion tons of uranium and copper, 500 million tons of silver and as much as 10 million tons of gold (or about 2.5 kg for each person on earth). This is not to imply that crustal rocks or sea water will be our future source of these minerals but rather to show that an immense supply exists. For example, considering gold, its average concentration in sea water ranges from 0.000004 to 0.000006 ml/l or about 50 lbs. per cubic mile of water. The value of the gold in a ton of sea water, however, is only one thousandth of a penny. The one major mineral resource that is in danger of being exhausted is oil and gas. Oil and gas are chemical compounds formed by biochemical processes, but require time periods in the order of millions of years for formation.

Supported by: *N.O.A.A. Sea Grant Program and ONR Contract N00014-74-C-0262;NR 083-004.*

OCEAN ENGINEERING

DEPARTMENT OF OCEAN ENGINEERING

Earl E. Hays, Department Chairman

ACOUSTICS

RAY CALCULATIONS OF OCEAN SOUND CHANNELS USING A POCKET PROGRAMMABLE CALCULATOR AND EXTENDED FORMS OF THE HIRSCH-CARTET MATHEMATICAL MODEL WITH TABLES OF THE INCOMPLETE BETA FUNCTION

Lincoln Baxter II

Ray calculations in good approximations to real acoustic conditions can be performed on a programmable pocket calculator by using a canonical family of profiles which lead to results expressable in tabulated Beta Functions and Incomplete Beta Functions. General properties of profiles fitted by layers using different parameters in the equation

$$C^2 = C_o^2(1 - (\alpha Z)^{\gamma})^{-1}$$

are discussed and reference is made to a supplement available from the Woods Hole Oceanographic Institution giving detailed programs, examples, and tables for practical computations.

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

COMPARISON OF HIGH-RESOLUTION NORMAL-INCIDENCE 3.5 kHz AND 12 kHz REFLECTIONS WITH GEOTECHNICAL PROPERTIES OF GIANT PISTON CORES

Willard Dow and Charles D. Hollister

A deep operating self-contained high-frequency echo sounder known as Deep Probe was recently developed at Woods Hole Oceanographic Institution under Energy Resources Development Administration (ERDA) and Sea Grant contracts for the purpose of resolving fine details of bottom and sub-bottom sediment layering in the deep ocean. In August 1975 this system was mounted on *R/V KNORR* for a coring expedition (*KNORR #51*) to the Rockall Trough area east of the United Kingdom under the direction of Dr. Charles Hollister.

The purpose of this exercise was to determine the correlation between the high frequency acoustic sounding records and the stratification of several Giant Piston Cores (GPC) taken in the same area.

Three of these cores, (GPC-13, 17 and 19, have been analyzed and compared graphically with the acoustic survey of each core location, using Deep Probe, near-bottom, both as a 12 kHz echo-sounder, and as a deep receiver for detecting returns from a 3.5 kHz pinger mounted on the surface vessel. The acoustic traces for both frequencies were then compared for detail and depth of penetration with respect to the cores.

Good to excellent correlation with core stratigraphy is indicated at 12 kHz. Resolution ranged from fair to poor at 3.5 kHz although transmission losses through the core were lower at this frequency.

The general conclusion is that deep-echo-sounding at 12 kHz is an excellent technique for delineation of shallow bottom and sub-bottom sediments in high detail, and that deep sounders have characteristics similar to Deep Probe could therefore prove valuable for detailed surveys of small areas preliminary to coring,or in deep-towed fish form, for general seismic profiling of shallow sediments over longer tracts in the deep ocean.

Supported by; *The Sandia Laboratories Contract* 07-7923.

AMPLITUDE FLUCTUATIONS OF ACOUSTIC SIGNALS RECEIVED FROM CONTINUOUS WAVE (CW) SOURCES TOWED IN THE DEEP OCEAN (U)

Kenneth D. Flowers, Dan J. Ramsdale, George V. Frisk and George R. Giellis

(U) This paper presents an empirical model of CW acoustic-signal-amplitude fluctuations as a function of frequency and range between the source and receiver. The data base is an experiment in which three sources (9.8, 110 and 262 Hz) were towed simultaneously by the *USNS HAYES* over a 3000 km track in deep water. The model is thus limited to a long-range (100 to 3000 km) deep-water application. The signal amplitude as received on bottom-mounted and suspended sensors near Bermuda, Puerto Rico, and Antigua was treated as being the result of a time-varying average (predictable) and a residual. The residual, i.e. the fluctuation about the average, was subdivided into 59 6-h intervals, each of which was then treated statistically. The coefficients of variation, skew, and kurtosis and the spatial-correlation length were then plotted vs range for each frequency.Analysis of these residual data showed (1) that there are no statistically significant differences between receiving sites, between the two high frequencies (110 and 262 Hz), or between bottom-mounted and suspended receivers;(2) that each statistic varies linearly with range between source and receiver; and (3) that the coefficients of variation and skew are uncorrelated and the coefficients of skew and kurtosis are linearly related. The only exception to (1) and (2) above is the behavior of the 9.8 Hz spatial-correlation length, which shows a strong dependence on receiving site and geometry. Removing the linear range trend from the data, a distribution for each statistic about the trend is determined. The trends

and their distributions are the model which describes the fluctuations of received signal amplitude as a function of frequency and range. The model may be used to generate a probability density function via Pearson's system of frequency curves.

Supported by: *Naval Electronic Systems Command.*

INHOMOGENEOUS WAVES AND THE PLANE WAVE REFLECTION COEFFICIENT

George V. Frisk

The importance of knowledge of the plane wave reflection coefficient R for a horizontally stratified medium at complex angles of incidence $\theta = \pi/2 - i\sigma$ $\langle \sigma > 0 \rangle$ is established. It is shown that for a point source, when the combined source/receiver is less than one-quarter wave length, these inhomogeneous plane waves can make significant contributions to the reflected field. But irrespective of source/receiver height, they are important when normal modes are excited in slow speed regions of the bottom via inhomogeneous-pure wave conversion, thus giving rise to poles in the reflection coefficient. The theory of inhomogeneous plane wave reflection is examined within the context of conservation of energy, and an expression for the intensity of these waves is derived. It is shown that although $|R|$ is bounded by unity for real incident angles, it can be unbounded for complex angles without violation of energy conservation. A general asymptotic result for R for large horizontal wavenumber is also derived. The computation of R for inhomogeneous waves is illustrated for three canonical bottom examples: (a) impenetrable, (b) isovelocity fluid, and (c) isovelocity fluid layer overlying an isovelocity fluid half-space.

Supported by: *ONR Contract N00014-77-C-0196.*

A TECHNIQUE FOR THE EVALUATION OF CIRCULARLY SYMMETRIC TWO-DIMENSIONAL FOURIER TRANSFORMS AND ITS APPLICATION TO THE MEASUREMENT OF OCEAN BOTTOM REFLECTION COEFFICIENTS

Alan V. Oppenheim, George V. Frisk, David R. Martinez

In a variety of applications the need arises for the evaluation of the two-dimensional Fourier transform of circularly symmetric functions. Because of the circular symmetry, the two-dimensional Fourier transform reduces to the Fourier-Bessel or Hankel transform. This paper considers a method for evaluating this transform using the "projection-slice" theorem for multi-dimensional transforms. The method is applied specifically to the measurement of the plane wave reflection coefficient of a horizontally stratified ocean bottom using the fact that for a point source, the bottom reflected field and the plane wave reflection coefficient are circularly symmetric and are related through a two-dimensional Fourier transform.

Supported by: *Advanced Research Projects Agency monitored by ONR Contract N00014-75-C-0591;NR 049-308; and in part by ONR Contract N00014-77-C-0196.*

ACOUSTIC MONITORING OF THE DISPERSION CHARACTERISTICS OF THE PARTICULATE PHASE OF INDUSTRIAL CHEMICAL WASTE AT DEEP WATER DUMP SITE 106

Marshall H. Orr and Frederick R. Hess

Acoustic monitoring of the particulate phase of industrial chemical waste has partially clarified the process by which the waste is dispersed in a water column with a sharp seasonal thermocline. The suspensates formed during the interaction of the chemical waste with seawater have been found to be trapped in the mixed layer or at the mixed layer boundary where they resided for extended periods of time. The trapping of the suspensates on the density structure within the mixed layer or at the mixed layer boundary results in a concentration of the particulate phase of the waste in a biologically active area of the water column.

Published in: *EOS, Transactions, Am.Geophy.Union,Vol.58(12), 1977.*

Supported by: *NOAA Contract 04-8-M01-43.*

REMOTE ACOUSTIC SENSING OF THE PARTICULATE PHASE OF INDUSTRIAL CHEMICAL WASTES AND SEWAGE SLUDGE

Marshall H. Orr

The seasonal variability of the dispersion of the particulate phase of industrial chemical waste has been studied at Deep Water Dump Site 106. The vertical dispersion of the particulates has been found to be strongly dependent on the depth of the mixed layer and the magnitude of the density gradient associated with the seasonal thermocline. During the late spring, summer and early fall months when a shallow seasonal thermocline exists (10-30 m) the particulates have been found to be confined within the mixed layer and on the density structure associated with the seasonal thermocline. During the winter months when mixed layers as deep as 180 m have been observed, the particulates have been observed to be diffusively

distributed throughout the mixed layer or to penetrate the mixed layer boundary.The variability in winter time distributions appears to be related to the density of the particles or waste type. Simple calculations based upon Stokes law are presented to reveal the impact of variable oceanic density structure on the sink rate of particles of differing density and radius and to indicate the need for incorporating these considerations into numerical models. The resulting need for high resolution CTD measurement at the dump site is also pointed out.

A short discussion of the necessity to include in the field experiments the measurement of both turbulence and shear in the water column is presented. The necessity of including a shear dependent calculation for the sink rates of particles in a shear flow in numerical modes is also discussed.

In particular, the adaptation of boundary layer theory for suspended sediment transport in rivers such as used in Raudkivi[1], is suggested. This approach has merits as Csanady[2] has recently demonstrated the potential applicability of the "law of the wall" to turbulent flow along a sharp density interface.

To be published in: *1st International Ocean Dumping Symposium Volume.*

Supported by: *NOAA Contract 04-8-M01-43.*

REMOTE SENSING OF NEAR SURFACE OCEANIC MIXING PROCESSES

Frederick R. Hess and Marshall H. Orr

Near surface oceanic mixing processes have been remotely sensed with high-frequency acoustic backscattering systems. A variety of mixing events have been identified. These include large (15 m) and small (1 m) scale shear instabilities, breaking short period internal waves, and entrainment at the base of the mixed layer. The mixed layer entrainment is thought to be caused by the formation of shear instabilities. Graphic acoustic records and some supportive data will be presented.

Published in: *EOS, Transactions, Am. Geophy.Union, Vol.59(12),Dec.1978.*

Supported by: *NSF Contract OCE-77-08682; NOAA Contract 04-8-M01-43; and NORDA Contract N00014-77-C-0196.*

REMOTE SENSING OF INTERNAL WAVES, ISOPYCNAL SURFACES AND INTERLEAVING WATER MASSES IN THE VICINITY OF HUDSON CANYON

Marshall H. Orr and Frederick R. Hess

Interleaving water masses, isopycnal surfaces, internal waves, and variations in suspended particle matter have been remotely sensed in the vicinity of Hudson Canyon using high-frequency acoustic backscattering systems. Graphic acoustic records, XBT and STD data will be presented and intercompared.The inverse root mean square deviation of the isopycnal surface displacement has been calculated and compared to the square root of the Brunt-Vaisala frequency.An interesting anomaly in the acoustic backscattering levels detected between the northeast and southeast banks of the canyon will be displayed.

Published in: *EOS, Transactions, Am. Geophy.Union, Vol.59(12), Dec.1978.*

Supported by: *NOAA Contract 04-8-M01-43; NORDA Contract N00014-77-C-0196.*

REMOTE SENSING OF PHYSICAL PROCESSES IN THE OCEAN USING HIGH FREQUENCY ACOUSTIC BACKSCATTERING SYSTEMS

Marshall H. Orr and Frederick R. Hess

High frequency acoustic backscattering systems are being used to remotely sense fluid processes in the oceanic environment. The systems are being used to detect and study short period internal waves, large scale Kelvin-Helmholtz instabilities, turbulence, interleaving water masses, frontal zones and variability of natural and man-introduced particle distributions. Graphic acoustic records will be presented demonstrating some of the results obtained to date.

Published in: *The Journal of the Acoustical Society of America, Vol.64, Supplement No.1, Fall 1978.*

Supported by: *NSF Contract OCE-77-08682; NOAA Contract 04-8-M01-43; NORDA Contract N00014-77-C-0196.*

ACOUSTIC PHASE TRACKING OF OCEAN MOORINGS

Robert C. Spindel, Robert P. Porter and John A. Schowerer

An acoustic tracking technique for monitoring the motion of deep ocean moorings is described. The system uses Doppler phase shifts from bottom-moored beacons to resolve 3-cm motions. The motion of two intermediate depth moorings is presented.

Published in: *IEEE Journal of Engineering, Vol.OE-3(1),Jan.1978.*

Supported by: *ONR Contracts N00014-70-C-0205;NR 083-325 and N00014-74-C-0262;NR 083-004.*

STATISTICS OF LOW-FREQUENCY MULTIPATH FLUCTUATIONS IN THE OCEAN

Robert Porter and Robert C. Spindel

Statistics of fluctuations of low-frequency sound in the ocean are analyzed for an arbitrary number of paths. Covariances are derived for the intensity, phase rate (time derivative of the phase), and related parameters. Power spectra are derived from the covariances. The multipath results are based on weakly fluctuating single paths whose phase is perturbed by the internal-wave field. The theory is illustrated by deriving some results for a single internal wave. We specialize to a large number of equal energy paths by appealing to the central-limit theorem which states that the Cartesian components for the multipath field are Gaussian distributed. Some results available in the literature are shown to be valid for the special case of a large number of paths. Power spectra for data obtained in a recent experiment are shown to follow the predictions of this analysis.

Published in: *Journal of the Acoustical Society of America,64(1),July,1978.*

Supported by: *ONR Contracts N00014-77-C-0196 and N00014-74-C-0262;NR-083-004.*

G E O L O G Y

THE GALAPAGOS RIFT AT 86°W, 3. SHEET FLOWS, COLLAPSE PITS AND LAVA LAKES OF THE RIFT VALLEY

Robert D. Ballard, Robin T. Holcomb and Tjeerd H. Van Andel

It has been known for some time that pillow basalts are a dominant feature of oceanic volcanism on mid-ocean ridges. Recent studies in the Cayman Trough, East Pacific Rise, and Galapagos Rift valley have shown that sheet flows are also an important component, especially on ridges with intermediate and fast-opening rates. In this paper, we describe the flow forms of such sheet flows observed in the Galapagos Rift valley. The principal forms are lobate, smooth, rippled and wrinkled sheet flows, as well as hackly and jumbled forms. Collapse pits of a wider range of sizes are common. Some of these are associated with vent areas, but most appear to have resulted from lava drainback, either as a consequence of downstream flow or, by drainback into the deeper plumbing system. Lava pillars are numerous around collapse pits and current evidence suggests that they most likely are spiracles of pipe vesicles produced by superheated water trapped below an advancing flow and rising through it to the flow surface.

Comparison with pahoehoe flow forms from Hawaii brings out many similarities.From these, we develop hypotheses regarding the flow process and conclude that the sheet flows of the Galapagos Rift valley can be considered a submarine equivalent of surface-fed pahoehoe, while the pillow basalts are analogous to subaerial tube-fed pahoehoe. This leads to a model that regards the difference between sheet flows and pillow basalts as the result of different eruption rates and degrees of channelization. In this model, the sheet flows and pillowed ridges of the Galapagos Rift are the analogs, respectively, of the early and late eruptive products of an Hawaiian eruptive event. The sheet flows represent early, brief but voluminous eruptions, followed by a more sustained, slower but steady eruptive phase that produced pillow basalts after an internal plumbing system has been well established. Thus pillowed volcanics should normally overlie sheet flow complexes of only slightly greater age.

This model leads to several different ways of explaining the distinction between the dominance of pillows on slow-spreading ridges and the sheet flow and pillow complexes of faster-spreading ridges.

Supported by: *I.D.O.E. Grants OCE75-23352 and OCE77-23978.*

RECENT GEOLOGY OF THE CHOTTS OF TUNISIA

James W. Mavor, Jr.

The region of the chotts, depressions with seasonal saline lakes, is widely accepted as the location of Lake Tritonis of Greek mythology. Appollonius of Rhodes, Diodorus Siculus and Plato probably described it. Various writers have suggested that the chotts were connected with the sea or inundated by the sea within the past several thousand years. The accepted geological history provides a basis for a permanent lake in the past which accords with the adventures of the Argonauts but the Oudref sill, a rock barrier 45 meters above sea level, has been intact for at least 50,000 years and only a prodigious tsnuami could have lifted water above it.

Published in: *Almogaren VIII/1977 Akedemische Druck u. Verlagsanstalt,Graz, Austria, 1978.*

INSTRUMENTATION

THE SEA-DATA 651-4 DATA LOGGER

David S. Hosom and Bradford Butman

This paper describes a digital data logger used as the primary controller and data collection device for the U. S. Geological Survey Sediment Monitoring Tripod Program. The tripods are deployed at sea in water depths up to 1000 feet for periods of three to four months. The system measures bottom current speed, direction, pressure, temperature, light transmission, and photographs the bottom.

This report is intended to provide a description of the unit and its operation.

TECHNICAL MEMORANDUM

Supported by: *U.S.G.S. Contract 14-08-001-15615.*

A SYSTEMS APPROACH TO UNDERWATER CAMERA DATA CORRELATION AND INTERPRETATION

Gary C. Hayward and William D. McElroy,Jr., Benthos,Inc. and David S. Hosom and William M. Marquet

By recording pertinent information relating to deep ocean photographs digitally on the film, it is possible to reduce significantly the labor involved in correlating ancillary operational and oceanographic data with the photographs. This paper discusses the details of such a system with specific reference to the one employed by the *DSRV Alvin.* In the *Alvin* system, time, depth, height off the bottom, compass bearing, and dive number are recorded on each picture. The data recording is accomplished by a 16-digit LED display photographed simultaneously with each picture. Circuit details of the system, as well as photographic examples are presented.

Supported by: *NSF Contract OF575-19029.*

A TRANSMISSOMETER-NEPHELOMETER AND CALIBRATION FACILITY

David S. Hosom and Bradford Butman

This paper describes a Transmissometer-Nephelometer that is modified for use on the United States Geological Survey Sediment Monitoring Tripod Program. This paper describes the modification, calibration, and operation of the instrument, as well as describing the facility developed to calibrate the instrument. The Sediment Monitoring Tripods are deployed in up to 1,000 feet of water for periods of three to four months. The system is intended for regional studies of sediment transport, and to determine the physical processes responsible for bottom movement.

Supported by: *U.S.G.S. Contract 14-08-001-15615.*

PREWIRED ENCAPSULATED STRAIN GAGES FOR HARD-TO-REACH LOCATIONS

Arnold G. Sharp

Resistance strain gages can be prewired and encapsulated by the user following the method outlined.The capsule becomes a compact, easily handled, waterproof unit that can be mounted in locations that would be considered inaccessible using conventional installation procedures. The present method has been used successfully in an application where strains were measured on the inside surface of a pressure vessel internally pressurized with water to 20,000 psi (138 MPa).

Supported by: *ONR Contract N00014-73-C-0097;NR 265-107.*

USE OF INDUSTRY STANDARDS FOR SHIPBOARD DATA SYSTEMS

Kenneth R. Peal and Albert M. Bradley

The problem of shipboard data acquisition is examined from a general point of view. A bus-oriented system is recommended where all elements of the system interface to a common bus. When the IEEE 488 bus is used, a wide variety of system controllers, tape units and printers can be used. System implementation is easy and the design remains basically unchanged as the system develops from an experimental one to a self-contained production unit. Bit serial current loop transmission is used for remote sensors providing noise immunity and easy system checkout.

Supported by: *NSF Contract OCE76-80174.*

DESIGN OF A STABLE FLOATING PLATFORM FOR AIR-SEA INTERACTION MEASUREMENTS

Henri O. Berteaux and Robert G. Walden

The design of an oceanographic platform can be defined as the rational specification of the platform dimensions and geometry. This specification is usually the result of an iterative process which compares the platform performance with the objectives to be reached and the logistic constraints to be met. This report describes such an exercise.

The scientific objectives - measurements of heat flux at the ocean surface - are first outlined. The limits of heave and roll motion compatible with the desired measurement accuracy are then established. Given the stochastic nature of platform response, these limits are stipulated in terms of expected means.

A review is then made, in some detail, of the analytical approach followed and of

the computer programs used to compute the statistical expectations of buoy heave and roll response to random sea excitation.

The next section of the report describes the comprehensive parametric study performed on some twenty different buoy configurations. The purpose of this study was first to investigate the dynamic response of a plausible base line design and of modified versions of the base line. A comparison of the dynamic response of these configurations could then be made, and the good features that this comparison would reveal could be used to design the buoy prototype. Following this approach a final configuration was specified which would meet the rather severe motion requirements (0.2 feet rms in heave and 5.0 degrees rms in roll in sea state 3).

The final section describes the techniques recommended to deploy and recover the 60 foot long buoy prototype.

Supported by: *THE JOHNS HOPKINS UNIVERSITY, APPLIED PHYSICS LABORATORY, SUBCONTRACT 600651.*

A MICROPROCESSOR ACOUSTIC DATA BUOY

Robert C. Spindel, Kenneth R. Peal, Donald E. Koelsch

A unique microprocessor controlled digital instrument has been developed for the remote acquisition of underwater acoustic data. The buoy is designed to receive and process long range, low frequency transmissions. Currently it processes complement phase maximal-length shift-register sequences with a carrier frequency of 220 Hz, receives and processes transmissions from nearby moored beacons for phase tracking of buoy motion, and continuously records ambient temperature and time. Matched or inverse filtering of the pseudorandom sequences allows separation of acoustic multipaths for individual study of amplitude and travel time fluctuations. Software control results in a flexible system that is readily reprogrammed to accommodate different transmission parameters and types. The primary advantage of the microprocessor controller is that it enables sophisticated *in situ* processing and significant power and space economy.

Supported by: *ONR Contracts N00014-77-C-0196 and N00014-74-C-0262;NR 083-004.*

OCEAN DYNAMICS

COMBINED WAVE AND CURRENT INTERACTION WITH A ROUGH BOTTOM

William D. Grant and Ole Secher Madsen

An analytical theory is presented to describe the combined motion of waves and currents in the vicinity of a rough bottom and the associated boundary shear stress. Characteristic shear velocities are defined for the respective wave and current boundary layer regions using a combined wave-current friction factor, and turbulent closure is accomplished by employing a time invariant turbulent eddy viscosity model which increases linearly with height above the seabed. The resulting linearized governing equations are solved for the wave and current kinematics both inside and outside the wave boundary layer region. For the current velocity profile above the wave boundary layer, the concept of an apparent bottom roughness is introduced, which depends on the physical bottom roughness as well as the wave characteristics. The net result is that the current above the wave boundary layer feels a larger resistance due to the presence of the wave. The wave-current friction factor and the apparent roughness are found as a function of the velocity of the current relative to the wave orbital velocity, the relative bottom roughness, and the angle between the currents and the waves. In the limiting case of a pure wave motion, the predictions of the velocity profile and wave friction factor from the theory have been shown to give good agreement with experimental results. The reasonable nature of the concept of the apparent bottom roughness is demonstrated by comparison with field observations of very large bottom roughnesses by previous investigators. The implications of the behavior predicted by the model on sediment transport and shelf-circulation models is discussed.

In Press: *Journal Geophysical Research (Oceans and Atmospheres)*

Supported by: *NOAA/AOML Contract 03-6-022-35220 and The Mellon Foundation.*

REFRACTIVE MICROSTRUCTURE FROM DIFFUSIVE AND TURBULENT OCEAN MIXING

Albert J. Williams 3rd

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.

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

THE ROLE OF DOUBLE DIFFUSION IN A GULF STREAM FRONTAL INTRUSION

Albert J. Williams 3rd

Double diffusive convection is possible where large vertical gradients in temperature and salinity tend to compensate in density. Frontal intrusions have these large gradients and can provide the possibility for a salt finger interface at one boundary and a diffusive interface at the other. But large vertical gradients of velocity are present at the boundaries of intrusions, which cause mechanical stirring and turbulent mixing as well. In the exceptionally active intrusions at the Gulf Stream Front near 38°N 69°W, a convective process resulting from incomplete mechanical mixing was observed photographically on both intrusive boundaries. The mechanism supposed for this convective process is as follows: shear instability initiates overturning which decays to finer scale turbulence; heat diffuses rapidly as the scale of the structure decreases; viscosity slows the mechanical stirring while the salinity differences remain, the mixed region now contains fluid both less dense and more dense than that adjoining the interface region; and convective plumes remove the positively and negatively buoyant fluid. The process is in effect "triple diffusion", depending on the diffusivity of momentum being much greater than the diffusivity of salt.

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

STATISTICS

CONFIDENCE INTERVALS FOR SIMILARITY MEASURES USING THE TWO-SAMPLE JACKKNIFE

Woollcott K. Smith, David Kravitz and J. Frederick Grassle

Measures of community similarity play an important role in the study of community structure and change over time. Similarity between two communities, say A and B, is usually estimated from relatively small samples taken from the two communities. Most discussions of similarity indices overlook this statistical problem. In this paper we assume that we have a random sample of individuals from both communities A and B. We can then apply an approximate method known as the two-sample jackknife (Miller, 1974) to obtain relatively unbiased estimates of the sampling variance. This method depends on forming a set of estimates from the original estimator by successively removing and replacing individuals from the two random samples.

Supported by: *Sea Bramt Contract 04-8-M01-149 and The Mellon Foundation.*

NOTES AND DISCUSSIONS ENVIRONMENTAL SURVEY DESIGN: A TIME SERIES APPROACH

Woollcott K. Smith

In general the goal of an environmental sampling program is to estimate some parameter of the population being studied. However, in most natural systems, that parameter is changing over time. A survey design must allocate sampling effort between sampling at a single time point and sampling over time. We have used results from sampling theory for stochastic processes to describe an efficient sampling program for estimating the mean of a time-varying parameter of the population. These theoretical results are applied to a three-year ichthyoplankton sampling program in Mount Hope Bay, Rhode Island.

Supported by: *NOAA Sea Grant 04-6-158-44016.*

MEASURES OF DIVERSITY WITH UNBIASED ESTIMATORS

Woollcott K. Smith, J. Frederick Grassle and David Kravitz

This paper describes a family of diversity measure that have unbiased estimators, and derives unbiased estimators for their sampling variances. The results of Smith and Grassle (1977) for the family of expected species diversity measures are reviewed. These results are applied to estimating vari-

ability in local diversity in the deep sea from small benthic cores. These results are extended to a wider class of diversity indices including a modification of Brillouin's index. Finally, unbiased estimation methods are applied to the estimation of species area diversity.

The basic intent of this work is to apply a well-known and straightforward statistical theory, unbiased estimation, that is valid for small samples. This requires a large increase in computational complexity of the estimators, but modern computers can easily handle this problem.

Supported by: *NOAA Sea Grant Contract 04-6-158-44016 and The Mellon Foundation.*

GENERAL

WEIGHT AND STABILITY OF DSRV ALVIN, *1278*

Arnold G. Sharp

The *ALVIN* weight and stability report for 1978 contains the usual programmed computations covering the normal submerged and normal surfaced vehicle configurations as well as a number of emergency conditions. Weight and stability figures also are reported for major vehicle subassemblies. Because of important structural modifications to *ALVIN* during the 1977-78 overhaul period the surface and submerged inclining experiments were conducted at the end of that period. The usual tethered trim dive also was performed and the results of these experiments are reported.

TECHNICAL MEMORANDUM

Supported by:*N00014-73-C-0097;NR 265-107.*

STRESS AND STRAIN IN MARINE PRESSURE VESSELS

James W. Mavor, Jr.

Most applications of pressure vessels in the marine environment are not covered by codes and laws. This text and handbook emphasizes methods for calculating failure pressure, stress and deformation. It includes an engineering description of the oceanic environment, detailed design of spherical and cylindrical pressure vessels, the neutrally buoyant submerged float, the pressure-retaining deep-sea sampler, the energy of high pressure vessels, deformation during descent, modes of failure, brittle fracture and selection of the safety factor.

A WATER SAMPLING SYSTEM FOR LONG DEPLOYMENT SEDIMENT MONITORING INSTRUMENT

David S. Hosom, Kenneth W. Doherty

This paper describes a water sampler system developed for use with the United States Geological Survey Sediment Monitoring Tripod Program. The tripods are deployed at sea in depths up to 1000 feet for periods of three to four months. After an initial (selectable) delay, the system takes a five-liter water sample based on a measurement of transmissivity by the standard tripod system. Up to six samples can be taken with (selectable) inter-sample delays during one deployment. At the time a sample is taken, a flag is set into the data-logger for correlation with measured data. The sample is preserved and analyzed later to correlate with the photographs, measured transmissivity, current speed and direction, pressure (from which wave height and frequency are determined), and temperature.

Supported by: *USGS Contract 14-08-001-15615*

PHYSICAL OCEANOGRAPHY

DEPARTMENT OF PHYSICAL OCEANOGRAPHY

Valentine Worthington, Department Chairman

OCEAN CIRCULATION

CURRENT SYSTEM SOUTH AND EAST OF THE GRAND BANKS OF NEWFOUNDLAND

R. Allyn Clarke, Harry W. Hill, Robert F. Reiniger and Bruce A. Warren

During April-June 1972 three ships conducted a survey of the region between the Grand Banks and the Mid-Atlantic Ridge, including a grid of hydrographic stations, and two long lines of near-bottom current-meter moorings across the Gulf Stream and North Atlantic Current respectively. The purpose was to map the property distributions and current field where the Gulf Stream branches, in greater detail and with less ambiguity than hitherto; that material is described here. Worthington's hypothesis that the primary current system there is not a branching Gulf Stream but portions of two separate (and non-geostrophic) gyres is criticized at length in terms of the observed property distributions; it is shown that, given a moderate degree of lateral mixing, they are consistent with the branching, geostrophic flow field, and that there is no need to abandon established physics in order to rationalize them. The deep motions recorded by the current meters on the North Atlantic Current line were roughly suggestive of the prevailing flow field inferred at shallower levels. No evidence of the Gulf Stream was found on the other line, however: rather, a burst of low-frequency eddy flow, which masked any prevailing extension of the Stream into the near-bottom water.

Supported by: *ONR Contracts N00014-66-C-0241;NR 083-004 and N00014-74-C-0262;NR-083-004.*

THERMAL FEEDBACK ON WIND-STRESS AS A CONTRIBUTING CAUSE OF THE GULF STREAM

Lloyd Regier, Henry M. Stommel and David Behringer

A simple model of wind-stress driven ocean circulation is constructed in which the surface temperature feeds back on the stress through a stability-sensitive drag coefficient. A concentration of streamlines somewhat similar to a separating Gulf Stream is produced, with only the linear Sverdrup dynamics.

Supported by: *NSF Grant OCE74-19782.*

THE BENJAMIN FRANKLIN AND TIMOTHY FOLGER CHART OF THE GULF STREAM, c. 1768.

Philip L. Richardson

Two printed copies of the original *c.* 1768 Franklin-Folger chart of the Gulf Stream have been found to exist in the Bibliothèque Nationale in Paris. This chart is the first good chart of the Gulf Stream; in the light of current oceanographic measurements of the Gulf Stream, the Franklin-Folger chart remains today an excellent summary of the main characteristics such as the mean path, width and speed of the Stream. A comparison of the 1768 chart with two later versions suggests that the *c.* 1778 Le Rouge version is a direct copy of the *c.* 1768 original and that the 1786 Poupard version (the most well-known) is a summary of the Le Rouge version but with some modifications.

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

RINGS, EDDIES

TRACKING A KUROSHIO COLD RING WITH A FREE-DRIFTING SURFACE BUOY

Robert E. Cheney, Philip L. Richardson, and Koichi Nagasaka

A cyclonic Kuroshio ring southeast of Japan was observed over a 50-day period in 1976 by XBT (expendable bathythermograph), STD (salinity, temperature, depth sensor), and a free-drifting surface buoy. The ring, estimated to be four months old, was 240 km in diameter and extended to a depth of at least 3000 *m*. The satellite-tracked buoy completed 6.5 revolutions around the ring during 37 days as the ring moved 150 km to the north. At the end of this period, the ring coalesced with the Kuroshio and during the next seven months the buoy drifted eastward 3500 km. Its downstream movement was influenced by a second cyclonic ring and anticyclonic eddies believed to be due to interaction of the Kuroshio Current with bottom topography.

Supported by: *NSF Grant OCE75-08765.*

THE BIRTH AND DEATH OF A WARM CORE RING

Gabriel T. Csanady

The birth of a warm core ring is conceptualized as a catastrophic separation process governed by the strong inertial forces within a western boundary current. A frictionless theory based on this postulate and assumed geostrophic balance on completion of the separation process yields a description of ring geometry and velocity distribution in first-order agreement with observation. In particular, maximum velocities of order 1 m sec^{-1} are predicted to occur near the perimeter. The initial decay rate of the ring is estimated from an interface friction and entrainment model (using the above maximum velocity) to be about 0.05 day^{-1}, which reduces rapidly, however, as the ring slows down. Interface fric-

tion is found to be much more important than entrainment in producing the decay.

In press: *J. Geophysical Research.*

Supported by: *Dept. Energy through subcontract with Brookhaven National Laboratory and National Ocean Survey of National Oceanic and Atmospheric Administration.*

A CENSUS OF GULF STREAM RINGS, SPRING 1975

Philip L. Richardson, Robert E. Cheneyk and Valentine Worthington

During 1975 several shipboard XBT (expendable bathythermographs) surveys plus satellite infrared imagery provided a nearly synoptic view of the distribution and number of Gulf Stream rings in the western North Atlantic. Twelve rings were identified; nine were cyclonic (cold core) rings and three were anticyclonic (warm core) rings. This is the largest number of rings ever observed during a short period of time (four months). The number is consistent with previous estimates of five to eight rings forming on each side of the Gulf Stream per year, each cyclonic ring with a life of one to two years and each anticyclonic ring with a life of six to twelve months. Evidence suggests that the mean movement of these rings was southwestward.

Published: *Journal of Geophysical Research* 83(C12)6136-6144 (1978).

Supported by: *NSF Grant OCE75-08765 and ONR Contract N00014-74-C-0262;NR 083-004.*

OBSERVATIONS OF ENERGETIC LOW FREQUENCY CURRENT FLUCTUATIONS IN THE CHARLIE-GIBBS FRACTURE ZONE

William J. Schmitz, Jr. and Nelson G. Hogg

Relatively energetic low frequency fluctuations in horizontal currents are found to exist below the thermocline in the northern gap of the Charlie-Gibbs Fracture Zone. For example, deep eddy kinetic energy levels there are about twice as large as those observed at similar relative depths in the MODE-I region. Eddy kinetic energies are about two to six times larger than mean kinetic energies. The vertical distribution of eddy kinetic energy is frequency dependent, increasing toward the thermocline for the longer time scales and intensifying toward the bottom at higher frequencies. In addition to the expected mean westward motion of Norwegian Sea Overflow Water through the northern gap of the fracture, rather consistent mean southerly flow is observed at depths just above the overflow.

In Press: *Journal of Marine Research.*

Supported by: *ONR Contract N00014-76-C-0197;NR 083-400.*

SURFACE LAYER PROCESSES AND METEOROLOGY

A NOTE ON THE MEAN CIRCULATION IN THE MID-ATLANTIC BIGHT

Robert C. Beardsley and Clinton D. Winant

Two possible mechanisms which may drive the observed mean alongshelf flow in the Mid-Atlantic Bight are described. Runoff from concentrated sources could conceivably force this flow; however, the one- and two-layer model results of Csanady (1978) and Beardsley and Hart (1978) show that the observed shelf flow cannot be driven by runoff alone. On the other hand, the Semtner and Mintz (1977) numerical model of the North Atlantic strongly suggests that the shelf circulation is just a boundary layer component of the ocean circulation and thus driven by the large-scale wind stress and heat flux distributions. This model result supports Csanady's (1978) conclusion that the physical mechanism which creates the alongshelf pressure gradient thought to drive the alongshelf flow must be of oceanic origin.

In Press: *Journal of Physical Oceanography, 9.*

Supported by: *NSF Grants OCE76-01813 (RCB) and OCE76-19494 (CDW).*

WIND EFFECTS ON SURFACE TO BOTTOM FRONTS

Gabriel T. Csanady

In nearshore regions, water of reduced density is frequently present owing to freshwater influx or spring heating. Under some circumstances, light nearshore water is confined to one side of a density front, extending from surface to bottom, and called 'spring thermocline' or 'shelf-edge front'. The shape and permanency of this front are affected by wind stress, which may interfere with the momentum balance in a direction parallel to the front and cause geostrophic adjustment motions normal to the front. A simple geostrophic adjustment theory elucidates some of the more important effects of wind on such fronts. Winds opposing the geostrophic flow above the inclined front tend to flatten its shape and eventually destroy the front, sometimes causing the formation of a surface 'lens' or 'bubble'. Comparison with observations from Lake Ontario and from the New England continental shelves shows that the theory gives a realistic first-order descroption of frontal behavior.

Published: *Journal of Geophysical Research 83:4633-4640 (1978)*

Supported by: *Dept.Energy through subcontract with Brookhaven National Laboratory (359133-S) and Great Lakes Environmental Research Laboratory of National Oceanic and Atmospheric Administration (03-5-022-26).*

SURFACE MIXING LAYERS IN THE SARGASSO SEA

Ann E. Gargett, Thomas B. Sanford, and Thomas R. Osborn

Vertical profiles of turbulent kinetic energy dissipation rate, baroclinic velocity, and related mean properties of the surface mixed layer and seasonal thermocline are presented from two occupations of a site in mid-Sargasso. Meteorological forcing during the first period of observations was sufficiently complex that no attempt is made to examine mixed layer dynamics. Dissipation values are characteristic of conditions during and following active wind forcing and should prove useful to theoretical attempts to include dissipation in surface mixed layer models. The second set of observations is both unique and amenable to a degree of quantitative analysis, owing to extremely light wind conditions. The turbulent kinetic energy balance is examined, in the context of Nider's 1975 integrated mixed layer model. Results indicate that the mixed layer turbulence was not being driven by the local surface wind/wave field, and suggest that at least one of the three major assumptions made, in various combinations, by the present generation of mixed layer models (local response, horizontal homogeneity, and slab response) is invalid in certain regions of the ocean.

Supported by: *ONR Contracts N00014-74-C-0262;NR 083-004 and N00014-76-6-0446; the Institute of Ocean Sciences, Patricia Bay.*

RECENT OBSERVATIONS IN THE EQUATORIAL INDIAN OCEAN

James R. Luyten

Little is known of the ocean's response to the monsoon regime winds over the western Indian Ocean beyond the Somali current along the western boundary. Recent measurements, consisting of velocity profiles over the full ocean depth near 53°E, have documented the existence of equatorially trapped, small vertical scale jets alternating in direction. This structure extends to roughly 2000 meters depth and appears to have a time scale of several months or longer. Moored current meter observations extending over nearly eight months indicate that the jet at 200 meters depth breaks down in mid-July, leaving an energetic, but not zonally coherent, eddy field. Recent theoretical results by various authors are reviewed in connection with the observational discovery.

In Press: *Proc.of Symposium on Monsoon Dynamics, New Delhi, 5-9 Dec.1977, J.M.Lighthill,editor.*

Supported by:*ONR Contract N00014-76-C-0197:NR 083-400 and NSF Grant ATM76-02196.*

WINTER CIRCULATION IN THE WESTERN GULF OF MAINE: PART 2: CURRENT AND PRESSURE OBSERVATIONS

John A. Vermersch, Robert C. Beardsley and Wendell S. Brown

The wintertime circulation in the western Gulf of Maine has been studied with a moored current, temperature, and pressure array which was deployed from November 1974 to January 1975. These observations have been interpreted with three additional data sets: coastal sea-level records, Portland Lightship meteorological data, and offshore hydrographic transect data which describe the evolution of the density field on weekly time scales. The observed mean currents are consistent with the idea of a cyclonic Gulf of Maine gyre.The subtidal current fluctuations were coherent in the vertical at each mooring but incoherent between the moorings which were separated by about 50 km in both the alongshore and offshore directions. Furthermore the currents showed only weak coherence with the winds.

The pressure field was highly coherent over the whole Gulf of Maine. Therefore, estimates of the pressure gradient vector inside and outside the 100 m isobath were made using coastal subsurface and bottom pressure records. The alongshore pressure gradient for the deeper water was found to be quite coherent with the winds for periods between 35 and 200 hours.

The incoherence between the observed current and pressure gradient fields is due in part to the existence of geostrophic cutrents associated with a highly variable density field. The density field variability is caused by incomplete mixing of three water masses; advected Scotian shelf water and deeper more saline slope water, and local winter water which is formed in the region of the experiment.

Supported by:*NSF Grants DES75-03992 and OCE76-02190 (WSB); DES74-03001 and OCE76-01813 (JAV and RCB).*

A COMPARISON OF SOME SHALLOW WIND-DRIVEN CURRENTS

Clinton D. Winant and Robert C. Beardsley

Four sets of current measurements made in water depths ranging between 28 and 38 m over periods ranging from three to five weeks are examined and compared. The response of the water column to wind forcing is examined by computing regression coefficients between the surface wind stress and two different parameterizations of bottom stress in terms of measured currents. Coefficients computed for the different data sets vary by as much as a factor of four. Although such variations might be due to instrumental differences, it appears more likely that the assumed dynamical balance between surface and bottom stress is incomplete, i.e., other forces such as the alongshore pressure gradient are quantitively important even in the relatively shallow waters studied. The observed decrease in near-bottom currents is consistent with a turbulent boundary layer characterized by a roughness height on the order of 20 cm.

Published: *Journal of Physical Oceanography, 9(1), 1979.*

Supported by: *NSF Grants OCE76-29494 (CDW) and OCE76-01813 (RCB).*

TURBULENCE AND MIXING, TOPOGRAPHICAL EFFECTS

EFFECTS OF VARIATIONS IN EDDY DIFFUSIVITY ON HORIZONTAL AND VERTICAL PROPERTY DISTRIBUTIONS IN THE OCEANS

Laurence Armi

A variable eddy diffusivity is used to describe property distributions found along and across isopycnal surfaces in the oceans. The gradient of the eddy diffusivity affects property distributions much like an additional velocity field from regions of high to regions of low eddy diffusivity. In support of such an interpretation, comparisons of the salinity distribution from the Mediterranean Outflow are made with an inferred eddy diffusivity field from the eddy potential energy field description of Dantzler (1977).A similar comparison is made for the vertical distribution of density with an apparent vertical eddy diffusivity due to boundary mixing and rapid along isopycnal exchange. Since the surface area available for boundary mixing is a function of depth (isopycnal level) this variation affects the distribution of density with depth.

Supported by: *NSF Grant OCE76-81190 and ONR Contract N00014-76-C-0197;NR 083-400.*

POLEWARD HEAT FLUX AND CONVERSION OF AVAILABLE POTENTIAL ENERGY IN DRAKE PASSAGE

Harry L. Bryden

Energetic fluctuations of periods longer than a day are found to transport heat poleward in the Drake Passage. Heat fluxes due to these low-frequency motions are large enough to account for all of the poleward heat transport across the polar front necessary to balance the heat lost to the atmosphere by waters around the Antarctic continent. Because of the poleward density gradient associated with the Antarctic Circumpolar Current in this region, these heat fluxes convert available potential energy into fluctuation potential and kinetic energies. The rate of conversion is found to be approximately equal to the rate at which wind puts energy into the water column. Comparisons are made with the baroclinic instability model which predicts conversion of available potential energy. The vertical phase function, which is suggested by several models to be a signature of the instability process, proved difficult to observe in these observations. The signature of the instability process for these observations is that temperature and poleward velocity are nearly in phase. Associated with this signature are a 90^{o} phase difference between poleward and eastward velocity components and a dominance of energy in the counterclockwise half of the rotary spectrum. The relationship between poleward heat flux and large-scale temperature gradient is found to agree within a factor of 2 with that obtained from consideration of the instability process in the atmosphere. Such agreement suggests that heat fluxes due to low-frequency motions may be parameterized in terms of large-scale temperature gradients in models of ocean circulation.

Published: *Journal of Marine Research.*

Supported by: *NSF Grants OCE76-80066 and OCE77-22887.*

ISLAND TRAPPED WAVES: THEORY AND OBSERVATIONS FROM AROUND BERMUDA

Nelson G. Hogg

From a triangular array of moored current and temperature recorders around Bermuda we have identified in the horizontal cross-spectra a number of periods ranging from 384 hr to 7.34 hr which are significantly coherent. In the sub-inertial range the phase estimates are consistent with waves of azimuthal mode number less than seven traveling clockwise round the island. In the super-inertial range we find it necessary to use both clockwise and anticlockwise propagating modes in order to interpret the phases using a lowest mode criterion. Although we find no significant auto-

spectral peaks a number of the periods we identify in the cross-spectra are near those found in autospectra closer to the island by Wunsch (1972) and Riser (1974).

We explore the theory of island-trapped waves in a homogeneous ocean. Although there are no perfectly-trapped Kelvin waves above the inertial frequency, there are leaky ones whose leakage decreases with azimuthal mode number and as the island radius increases. In this way there is a smooth transition to the straight coastline case. Addition of a sloping skirt to the island introduces both low frequency topographic modes and high frequency edge waves as well as improving the efficiency of trapping of Kelvin waves.

The question of excitation is also discussed. In addition to the mechanisms of weather forcing and internal wave scattering suggested by Wunsch (1972) for generation of the sub-inertial and super-inertial waves, respectively, we suggest that the transient interaction of Gulf Stream rings with the island could be a source of energy for the waves.

Supported by: *ONR Contracts N00014-74-C-0262;NR 083-004 and N00014-76-C-0197;NR 083-400.*

THE ANATOMY OF THE ANTARCTIC POLAR FRONT IN THE DRAKE PASSAGE

Terrence M. Joyce, Walter Zenk, and John M. Toole

An intensive three-dimensional survey of the Antarctic Polar Front was made in the Drake Passage in March 1976. The front, which was imbedded within one of the high velocity cores of the circumpolar current is viewed as a water mass boundary demarking the northern extent of near-surface Antarctic waters.Within the front water masses are observed to intrude, one above the other, with characteristic vertical scales of 50-100 meters. The intrusions are horizontally anisotropic, being elongated in the along-stream direction and constrained to the upper 800 meters of the front. The spatial and temporal persistence of the variability is examined through the analysis of continuous vertical profiles of horizontal velocity temperature, salinity, oxygen with discreet sampling of nutrients. Analysis of the velocity data showed the mean current flowing to the NNE with speeds of $O(30\text{-}40\ cm\ sec^{-1})$ in the upper 600 meters, with temporal variability over a 28-hour 'yo-yo' due primarily to internal gravity waves. The thermohaline variability was not wave-induced but rather associated with nearly insentropic advection of different water masses across the front. Cold fresh and warm salty intrusions did not conserve potential density, however, and double-diffusive transfers are strongly suggested. Applying a model for lateral mixing we estimate poleward temperature and salinity fluxes due to interleaving of $.086^{o}C\ cm\ sec^{-1}$ and $.069\ ^{o}/_{oo}\ cm\ sec^{-1}$ respectively. If these are typical, interleaving could play a significant role in large-scale balance of salt and to a lesser extent heat for the Southern Ocean.

Published in: *Journal of Geophysical Research 83(C12) 6093-6113, 1978.*

Supported by: *NSF Grants OCE75-14056 and OCE77-82036.*

GEOSTROPHIC TURBULENCE

Peter B. Rhines

Geostrophic turbulence is the chaotic, nonlineat motion of geophysical fluids at large length- and time-scales. It describes much of the 100 km-scale motion in the oceans, and 1000 km-scale motion in the atmosphere. The governing equation expresses the conservation (but for forcing and dissipation) of potential vorticity, following fluid particles. This simple constraint means that knowledge of the kinematics of particle dispersion in the flow gives us direct information about the evolution of the length-scales of the flow, the release of potential energy, and development of the vertical structure, and the induction of mean circulation by the eddies. This paper includes a review of much current work in the field.

Published in: *Annual Review of Fluid Mechanics, 11:401-441 (1979).*

Supported by: *NSF Grants OCE76-00992 and OCE75-21674.*

INTERNAL WAVES

INTERNAL WAVE VARIABILITY DURING THE INTERNAL WAVE EXPERIMENT (IWEX)

Claude Frankignoul and Terrence M. Joyce

The relation between internal wave variability and larger and smaller scales of motion is investigated, using the IWEX data set. To investigate the role of internal waves in the vertical diffusion of large scale momentum, the time variability of the vertical flux of horizontal internal wave momentum (estimated from temperature and current data), is compared to that of the mean vertical shear. It is found that internal waves cannot cause a vertical viscosity as large as proposed by Müller (1976), but that the data are too noisy to detect a possible wave-induced viscosity in absolute value of the order of $10^{-2}m^{2}s^{-1}$ or less. Similarities in the time behavior of the total internal wave energy and that of the

square mean vertical shear suggest that some kind of dynamical coupling exists between internal waves and larger scale flows.There is some evidence that the level of temperature fine-structure activity also varies in a related way. An analysis of CTD station data taken during MODE demonstrates the mappability of the fine-structure activity, and again suggests a relation with the geostrphic eddy flow.

In Press: *Journal of Geophysical Research.*

Supported by: *ONR Contracts N00014-74-C-0262:NR 083-004 and N00014-76-C-0197;NR 083-400; Applied Physics Laboratory of The Johns Hopkins University Contract 372111: NSF Grant OCE74-19782.*

FINE STRUCTURE IN THE ANTARCTIC POLAR FRONT ZONE: ITS CHARACTERISTICS AND POSSIBLE RELATIONSHIP TO INTERNAL WAVES

Daniel T. Georgi

Temperature and salinity data from a repeated salinity-temperature-depth station and temperature profiles from three expendable bathythermograph experiments are used to investigare both the spatial and the temporal characteristics of fine structure observed in the Antarctic Polar Front Zone. The fine structure was found to evolve considerably on time scales of one hour and less. From an experiment designed to elucidate the spatial scales of the fine structure, a marked anisotropy was revealed, suggesting that the temperature structures were elongated filaments aligned with the front. The data were also used to investigate the possibility that internal waves generate the observed fine structure. On the basis of the temperature-salinity correlation of the fine structure and the extremely large required vertical displacements, the vertical motions of internal waves can be ruled out as the primany cause of the fine structure. Because the Antarctic Polar Front Zone is a region of high horizontal temperature and salinity gradients and because of an observed increase at one-half inertial period in drop-lagged coherences, it is hypothesized that the low frequency, nearly horizontal internal wave motions are generating the observed fine structure. However, in the particular case where direct observations of the vertical motions of internal waves were available, assuming the relationship between vertical and horizontal displacements prescribed by the Garrett and Munk (1975) model holds, horizontal displacements are also ruled out as the sole source of the observed fine structure, yielding neither enough total variance nor the expected spectral shape; thus, much of the observed variability may be attributed to temperature fine structure of noninternal wave origin.

Published in: *Journal of Geophysical Research 83(C9): 4579-4588 (1978).*

Supported by: *NSF Grants OCE74-15062 and OCE75-14056.*

TIDALLY-GENERATED INTERNAL WAVE PACKETS IN MASSACHUSETTS BAY, U.S.A.; PRELIMINARY PHYSICAL AND BIOLOGICAL RESULTS

Loren R. Haury, Melbourne G. Briscoe and Marshall H. Orr

Observations in Massachusetts Bay of high-frequency internal wave packets indicate they are caused by lee waves generated outside a submarine bank at the Bay's seaward margin during ebb tide. The lee waves propagate into the Bay as the tide turns to flood, steepen nonlinearly, and develop into the packet. A 200 kHz acoustic backscattering system detected the evolution of the packets. Large overturning events were observed acoustically and in density profiles. Plankton distributions undergo strong vertical displacements and mixing associated with the wave packet passage.

Supported by: *NORDA (Naval Ocean Research and Development Activity); N00014-77-C-0196: NOAA 04-6-158-40072; NSF OCE77 8682.*

VERTICAL COHERENCE OF THE INTERNAL WAVE FIELD FROM TOWED SENSORS

Eli J. Katz and Melbourne G. Briscoe

Constant depth and isopycnal-following tows are used to estimate the towed vertical coherence of the internal wave field, at vertical separations of 8.5, 18, 28, and 70 m. The depths of the tows are approximately 750 m at the maximum of the buoyancy frequency in the main thermocline of the Sargasso Sea, and near 350 m in the buoyancy frequency minimum between the main and seasonal thermocline.

The towed spectra and towed vertical coherence are compared with three model spectra (GM75, GM76, and IWEX): at 750 m the agreement between data and models is very good, with IWEX being slightly better. At 350 m several of the measured towed vertical coherence spectra are more complex than the spectra from the deeper tows: there are anomalously high coherences in a band from 0.7 to 2 cycles per kilometer that are not predictable by the models. We suggest this coherence bump may be evidence of Eckart resonance, i.e., modes tunneling between the

two thermoclines into the region of low buoyancy frequency.

In Press: *Journal of Physical Oceanography 9(3) (1979).*

Supported by: *NSF Grant OCE74-19608 and ONR Contract N00014-74-C-0262;NR 083-004.*

OBSERVARIONS OF INTERACTION BETWEEN THE INTERNAL WAVEFIELD AND LOW FREQUENCY FLOWS IN THE NORTH ATLANTIC

Barry R. Ruddick and Terrence M. Joyce

A total of four moorings from POLYMODE Array I and II were analyzed in an investigation of internal wavefield-mean flow interactions. In particular, evidence for wave-mean flow interaction was sought by searching for time correlations between the vertically-acting Reynolds stress of the wavefield (estimated using the temperature and velocity records), and the mean shear. No significant stress-shear correlations were found at the less energetic moorings, ($\bar{u} \lesssim 10$ cm s^{-1}), indicating that the magnitude of the eddy viscosity was under 200 cm^2 s^{-1}, with the sign of the energy transfer uncertain. This is considerably below the $O(4500$ cm^2 $s^{-1})$ predicted by Müller (1976). An extensive error analysis indicates that the large wave stress predicted by the theory should have been clearly observable under the conditions of measurement. At moorings typified by a higher mean velocity ($\bar{u} \sim 25$ cm s^{-1}), statistically significant stress-shear correlations were found, and the wavefield energy level was observed to modulate with the strength of the mean flow. The observations were consistent with generation of short (about 1 km horizontal wavelength) internal waves by the mean shear near the thermocline, resulting in an effective eddy viscosity of about 100 cm^2 s^{-1}.

Theoretical computations indicate that the wavefield "basic state" may not be independent of the mean flow as assumed by Muller, but can actually be modified by large-scale vertical shear and still remain in equilibrium. In that case, the wavefield does not exchange momentum with a large-scale vertical shear flow, and, excepting critical layer effects, a small vertical eddy viscosity is to be expected. Using the Garrett-Munk (1975) model internal wave spectrum, estimates were made of the maximum momentum flux (stress) expected to be lost to critical layer absorption. This stress was found to increase almost linearly with the velocity difference across the shear zone, corresponding to a vertical eddy viscosity of ~100 cm^2 s^{-1}. Stresses indicative of this effect were not observed in the data.

In Press: *Journal of Physical Oceanography.*

Supported by: *ONR Contract N00014-76-C-0197;NR 083-400.*

THEORETICAL MODELS

AN EXPERIMENTAL AND NUMERICAL STUDY OF THE SECULAR SPIN-UP OF A THERMALLY STRATIFIED ROTATING FLUID

Robert C. Beardsley, Kim D. Saunders, Alex C. Warn-Varnas and John M. Harding

Laboratory and numerical experiments have been conducted to study the secular spin-up of both a homogeneous and a thermally-stratified rotating fluid in a right cylinder. In these experiments, the angular velocity of the container increases linearly in time from an initial rotation rate at t = 0. A simple quasi-geostrophic model is developed to describe the adjustment of the fluid over the characteristic spin-up time scale to the constant angular acceleration of the basin. Good agreement is found between the observed interior temperature and azimuthal velocity fields and theory in both the homogeneous and stratified secular experiments. This result is in contrast to the much faster adjustment observed in stratified instantaneous spin-up experiments reported earlier. The main difference between these experimental cases is the inability of secular forcing to excite energetic inertial-gravity wave transients during the initial phases of secular spin-up.Thus, the asymptotic theory which has filtered out these initial higher frequcncy transients is accurate even though the inertial period is not much smaller than the characteristic spin-up time scale.

In Press: *Journal of Fluid Mechanics.*

Supported by: *NSF Grants A-30626X1, OCE73-00528 and OCE76-01813 and NORDA (Naval Ocean Research and Development Activity).*

MEAN FLOW GENERATION BY TOPOGRAPHIC ROSSBY WAVES

Alain Colin de Verdiere

This paper makes use of the ease of modeling topographic Rossby waves in a laboratory context to investigate the ability of these waves to generate strong zonal mean flows when the geostrophic (f/H) contours are closed. A zonally traveling wave is forced in a narrow latitude band of a "polar beta plane".Stronger signals occur when the driving moves retrograde and at the phase speed of the free gravest modes. An important zonal westward mean flow occurs in the free interior while a compensating eastward jet is found at forced lat-

itudes. Dependence of the mean flow strength upon the wave steepness indicates that genuine rectification processes are indeed taking place when the fluid is stirred by purely oscillating devices.

This general tendancy for topographic Rossby waves to transfer energy to zonal components is first analyzed theoretically by investigating a side band instability mechanism within an unforced fluid. Among the product of the interactions between a primary wave of wavenumber $\vec{K}$ and its side bands of wave number $\vec{K} \pm \vec{\delta K}$, the zonal flow emerges prominently. Wave steepness of order $(|\vec{\delta K}|/|\vec{K}|)^{1/2}$ only are required for zonal energy to grow whereas any other components of scale larger or shorter than the primary wave need huge steepness (of order $(|\vec{\delta K}|/|\vec{K}|)^{-\frac{3}{2}}$) for amplification.

For gentle driving certain classical aspects of Rossby wave propagation can be checked against the experiments. The linear theory provides also a convenient framework to discuss the meridional structure of the wave-induced Reynolds stress. For more energetic driving, a test of the potential vorticity mixing theory can be carried out and draws further light upon the rectification mechanics.

Supported by: *NFS Grant OCE74-21674.*

AN EXAMPLE OF EDDY-INDUCED OCEAN CIRCULATION

William R. Holland and Peter B. Rhines

This paper is a complement to the previous theoretical discussion (Rhines and Holland, 1978) of eddy-induced oceanic and atmospheric circulations. Here we carry out detailed vorticity analysis of a single numerical experiment, a two-gyre circulation driven by steady winds. Local and area-average vorticity budgets and vector potential vorticity fluxes are discussed. Nowhere in this 1000 km by 2000 km basin is there an extensive region of Sverdrup balance.

The experiment is compared with a detailed application of vorticity-transport theory, which predicts the mean abyssal circulation, given the mean flow of the upper layer and an approximate map of eddy intensity. Theory and experiment agree, that the abyssal circulation is driven from above by inviscid 'wave' drag exerted by the thermocline eddies. Even when the deep-ocean velocities are small, the deep transport can exceed that of the thinner upper layer.

Supported by: *National Center for Atmospheric Research and NSF Grants OCE75-21674 and OCE76-00992.*

ON THE MEDITERRANEAN OUTFLOW IN THE NORTH ATLANTIC: PART I, 2-D ADVECTIVE DIFFUSIVE MODEL WITH A MID-OCEAN RIDGE

Terrance M. Joyce

A steady, 2-D, advective-diffusive balance is applied to a model North Atlantic Ocean in order to study the effect of a zonal mid-ocean ridge upon the salinity distribution of the Mediterranean outflow. The nondimensional ratio of horizontal advection to diffusion, the Peclet number, P, is varied to obtain the correct shape for the distribution with a flat bottom. For P = 10, the effect of a Gaussian zonal ridge is then studied for differing ridge heights, widths, and locations. For a lateral diffusivity of .5-1 x $10^3 m^2$/sec, realistic salinity anomaly fluxes will support a volume transport thru the tongue of 5-10 x $10^6 m^3$/sec for P = 10. Furthermore, the effect of the ridge upon the tracer distribution is to support a weak front over the topography of scale comparable to the width of the ridge and with amplitude varying with ridge height and location. Results of this model will be compared in Part II to a CTD section across the mid-Atlantic Ridge southwest of the Azores. The model is offered as the simplest extension of previous work capable of supporting a mid-depth front over the ridge in the Mediterranean salinity anomaly distribution.

Supported by: *ONR Contract N00014-76-C-0197;NR 083-400.*

SIMULATED DYNAMIC BALANCES FOR MID-OCEAN MESOSCALE EDDIES

W. Brechner Owens

Eulerian potential vorticity and heat balances calculated for a multi-layered quasi-geostrophic model are shown to be consistent with those inferred from the MODE data. Above the thermocline the balances are the result of the turbulent cascade of relative vorticity which creates a gap between centers of mass of enstrophy and energy spectra so that relative vorticity nearly acts as a passive scalar. In the Lagrangian frame this advective effect is suppressed and one observes a coupled response by relative vorticity and vertical vortex stretching to changes in planetary vorticity. In the bottom layer there is a time-mean flow following f/H contours which is the consequence of a down-gradient flux of vorticity. Superposed on this flow are topographic Rossby waves. The intermediate layers have a balance which is a mixture of those described above.

In Press: *Journal of Physical Oceanography, April 1979.*

Supported by: *NSF Grant OCE76-00992.*

EDDY-DRIVEN CIRCULATION OF THE OCEAN: A VORTICITY-TRANSPORT THEORY

Peter B. Rhines

A formulation is given of the equation for turbulent, potential vorticity (q-) conserving flow, which describes the generation of Eulerian mean-motion fields by eddies and waves. Effects of external stresses, heat flux, dissipation and transience are included, which can reverse the normally down-gradient transport of q.

The 'net' eddy flux of q is a rotational stress, acting transversely to its direction, on the Eulerian-mean fluid. In the atmosphere the *north-south* q-flux yields a zonal acceleration (or surface drag) in a familiar manner. In the ocean, however, the same flux, integrated over the volume, gives an integral measure of the western intensification of energy, as well as the production rate of eddy potential enstrophy.

The main quantitative application is a model of the abyssal Eulerian mean motion beneath a (known) energetic, closed mean surface circulation. The deep mean velocities are predicted to have strength κ/L_M, independent of the mean q-gradients, where κ is the Lagrangian diffusivity, and L_M the scale of κ or q, whichever is smaller. This abyssal flow involves, typically, two gyres beneath each upper-level gyre, and shows some of the intense behavior found at sea, in the recirculation found on either side of the separated Gulf Stream, and in the Western Boundary Undercurrent. The force causing this spin-up of the deep ocean is principally an inviscid form-drag exerted by the moving thermocline eddies (rather than involving strong Reynolds' stress divergence). The deep induced ocean flows differ essentially from their atmospheric counterparts, the lower-level winds beneath the westerly midlatitude jet.

For energy levels appropriate to the ocean, the beta-effect keeps the more intense induced gyres small in scale (a few hundred km).But also, by driving flow across mean geostrophic contours, the eddies provide a mechanism for closing the laminar, adiabatic circulation which exists at much larger scale (the laminar circulation must, itself, follow q-contours when far from side-, top-, or bottom boundary layers). When the geostrophic contours extend far pseudo-westward from the turbulent region,the eddies can, themselves, be the prime driving agent for the distant 'quiet' ocean.

When strong, large-scale bottom slopes are present, the model becomes more predictive, requiring knowledge only of the diffu sivity of the eddies (and not of the upper-level flow structure). This suggests the possibility of 'non-classical' abyssal boundary currents, driven along the continental rise by eddies somewhere above the same q-contour. It also predicts the time-averaged contour circulations above ocean rises, found to dominate certain numerical models. The zonally symmetric version of this formulation shows bands of zonal current to develop in response to geostrophic eddies, as are seen in models of the atmospheres of the Earth and Jupiter.

The Lagrangian-mean flow differs from these Eulerian-mean motions, by a comparable turbulent Stokes drift. Under special circumstances, for inviscid fluid, the Lagrangian flow vanishes. The turbulent dissipation of perturbation potential vorticity in real fluids is essential to the development of particle flow across large-scale geostrophic contours.

Detailed comparison with Holland's (1977) numerical model of the ocean will be given elsewhere.

Supported by: *NSF Grant OCE75-21674 and ONR Contract N00014-76-C-0197;NR 083-400.*

A THEORETICAL DISCUSSION OF EDDY-DRIVEN MEAN FLOWS

Peter B. Rhines and William R. Holland

This is a discussion of the formulation of eddy-driven mean circulation in terms of potential vorticity (q-) transport. The net eddy-transport of q in an isopycnal layer equals the net rotational stress (at right angles) exerted by the perturbations on the mean fluid at a point. The interfacing of turbulent and classical, laminar oceanic regions is described. Waves and eddies are capable of generating circulation locally, and also of transmitting it over great distances along mean geostrophic contours, Q = constant,hence determining the flow in quiet parts of the ocean. Examples are given which stress the difference between 'atmospheric' geometry (free, closed Q-contours) and 'oceanic' geometry (blocked or open contours).

Vorticity transport theory takes the Lagrangian particle diffusivity, κ . and the mean, initial Q-field, and from these infers the Eulerian induced mean motion. The key assumption is that the scale over which κ and Q vary far exceeds the typical fluid particle displacement. With linearized waves of instabilities the diffusivity is calculable, as in Green's work. In a specific case, the average stress exerted by a Rossby-wave packet on the mean fluid is just the gradient of the average kinetic energy density reflected about the wave-vector, $\underset{\sim}{k}$. With geostrophic turbulence, instead, κ must be inferred from the supercriticality of the pre-existing flow, and

geometry of Q, or otherwise observed or estimated.

The induced Eulerian mean motion has strength $\langle u_e \rangle \sim \kappa / L_m$, where L_m is the lesser of the lateral scales of variation of Q and κ, in the case of blocked or open contours; With closed Q-contours the flow is much faster, $\langle u_e \rangle \sim \kappa \nabla Q / \lambda$ where λ is the retarding bottom friction.

The Lagrangian-mean cross-contour flow is comparable with the Eulerian-mean for free Q-geometry, yet is far smaller in the presence of blocked contours. Non-conservative effects (external forcing or a strong enstrophy cascade) are essential to persistent particle motion across geostrophic contours. Only when the perturbation field is strong enough to be turbulent, do the induced circulations become of practical interest. Observations of κ at sea suggest that eddies exert stresses equivalent to one dyne cm^{-2} of wind-stress even in quiet parts of the gyre.

The principal value in analyzing the potential vorticity transport is that its sense and nature are predictable (as opposed to the equivalent Reynolds stress and Coriolis torque effects in the momentum balance). In a stationary turbulence field, beneath the depths of direct external forcing, the potential vorticity flux must have a component down the mean Q-gradient, provided that small-scale processes act to dissipate the potential enstrophy.

Supported by: *National Center for Atmospheric Research and NSF Grants OCE75-21674 and OCE76-00992.*

OTHERS

CALCULATION OF THE POTENTIAL TEMPERATURE OF SEAWATER FROM THE EFFECT OF PRESSURE ON ENTROPY

Alvin L. Bradshaw

A method of calculating the potential temperature using the pressure integral of the temperature derivative of specific volume is described. The estimation of the uncertainty due to errors in the thermal expansion and specific heat data is straightforward. A comparison is made with values found by Bryden (1973) from integration of the adiabatic gradient, the same expressions for the temperature derivative and the specific heat being used in both cases. The results agree within the fitting error in Bryden's polynomial for potential temperature at $35^{o}/_{oo}$ salinity but Bryden's estimate of the uncertainty in his values is too large.

In Press: *Deep Sea Research.*

Supported by: *NSF Grant IDO74-18158.*

GEOSTROPHIC VORTICITY BALANCE IN MID-OCEAN

Harry L. Bryden

Estimates of advection of planetary vorticity and of vortex stretching from moored current meter measurements of eight months duration in the western North Atlantic balance within small errors. This result is a first confirmation of the geostrophic vorticity balance which is widely used in models of large-scale circulation in the mid-ocean.

Supported by: *ONR Contract N00014-76-C-0197;NR 083-400; NSF Grants OCE77-19403 and OCE77-22887.*

THE MEAN PRESSURE FIELD OF THE NORTH ATLANTIC

Gabriel T. Csanady

Three additive contributions to the global surface elevation distribution in an oceanic basin may be identified: one, ζ_1 (x,y), a direct response to the internal distribution of mass, another, ζ_2 (x,y) in geostrophic balance with depth-integrated flow induced by wind-stress curl in the classical manner, and a third, ζ_3 (x,y) in geostrophic balance with depth integrated flow caused by thermohaline effects. The first component, ζ_1 is associated with internal flow akin to those in baroclinic modes of constant depth models, the depth integrated transport of this flow component being negligible. The second component ζ_2, is much as calculated in classical models of wind-driven circulation. Applied to a "real" oceanic basin, however, allowance must be made for the decisive influence of steep bottom slopes, which act effectively as vertical walls on the abyssal gyre. In the western North Atlantic the main gyre is thus confined between the continental margin of North America and the Mid-Atlantic Ridge. The third (thermocline) component of the pressure field seems to be mainly important along continental margins and may well be responsible for the southwestward flow of the continental shelf waters north of Cape Hattaras.

The pressure and circulation fields over steep slopes are governed by an equation of boundary layer character, akin to the equation of heat conduction. This explains why steep slopes "insulate" abyssal gyres from pressure fields trapped over upper slopes and shelves.

Supported by: *Department of Energy through subcontract with Brookhaven National Laboratory entitled "Coastal Transport and Diffusion".*

MODAL PROPERTIES OF ANTARCTIC INTERMEDIATE WATER IN THE SOUTHEAST PACIFIC AND THE SOUTH ATLANTIC

Daniel T. Georgi

Modal properties of Antarctic intermediate Water (AAIW) are determined from bivariate distribution diagrams for two regions in the Southeast Pacific and two regions in the South Atlantic. The volumetric potential temperature-salinity diagrams reveal distinct differences between the intermediate waters of the Southeast Pacific and the South Atlantic. The intermediate waters of the Southeast Pacific are more homogeneous than their counterpart in the South Atlantic. The potential temperature and salinity properties of the large volume mode intermediate water in the Southeast Pacific are identical to the coldest variety of McCartney's (1977) Subantarctic Mode Water (SAMW). It is evident from volumetrically weighted average properties that the intermediate water of the South Atlantic is primarily colder ($\sim$1°C), denser ($\sim$.1 mg/cm^3) and oxygen poorer (.5mℓ/ℓ) than the intermediate water of the Southeast Pacific.

If it is assumed that no Antarctic Intermediate Waterformation takes place in the South Atlantic outside of the Drake Passage and Scotia Sea, then this temperature difference implies that a substantial heat loss takes place during the transit from the Southeast Pacific to the Southwest Atlantic. This heat loss can be the result of a horizontal heat flux divergence and/or a vertical heat flux divergence. Assuming that the poleward heat flux at the northern boundary as compared to the southern boundary of the SAMW is small and that the heat flux to the atmosphere is large compared to the heat flux from the deep waters, then a heat loss for the SAMW can be calculated which is the result of a poleward heat flux at the southern boundary and/or a heat flux to the atmosphere. As such, these heat fluxes are compared with recently calculated poleward and cross sea-surface heat fluxes. The poleward heat flux due to temperature finestructure, interleaving, or intrusions is found to be inadequate to account for the difference in temperature, while the poleward heat flux due to low frequency motions and the estimated heat flux to the atmosphere are both found to be of the right order of magnitude but a factor of two too small. However, these results must be considered preliminary because of the uncertainties in the winter hydrographic conditions and the lack of heat flux divergence measurements.

In Press: *Journal of Physical Oceanography, 9(3).*

Supported by: *NSF Grant OCE76-81449 and W.H.O.I.Postdoctoral Scholarship.*

A DEPTH CONTROLLED TOW SYSTEM FOR HYDROGRAPHIC AND CURRENT MEASUREMENTS WITH APPLICATIONS

Eli Joel Katz and Warren E. Witzell, Jr.

A towed body with variable positive lift controlled by shipboard command has been towed for a total of 8000 kms since 1973 without fairing or special winch. The system operates on a single conductor wire sharing power, data, and control signals with transmission to shipboard by frequency shift key modulation. Examples of constant depth, isopleth following, and rapid and step-like vertical sampling are presented. Depths of 800 m at a tow speed of 3 mps, with controlled vertical lift of up to 200 m, have been achieved. Three developments of secondary bodies, towed by the controlled fish, are described. They shroud commercially available sensors measuring pressure, temperature, conductivity, dissolved oxygen, speed, heading, pitch and roll. Experience with a towed acoustic back-scattering current sensor system is detailed.

In Press: *Deep Sea Research.*

Supported by: *ONR Contracts N00014-70-C-0205, N00014-74-C-0262 and N00014-77-C-0196; NSF Grants GX34906, ATM73-00344 and OCE74-19608.*

SCALES OF MOTION IN THE SUBTROPICAL CONVERGENT ZONE

Ants Leetmaa and Arthur D. Voorhis

Satellite infrared data show that the sea surface temperature pattern in the subtropical convergence consists of meridionally oriented, alternating warm and cold plumes with a wavelength of about 200 kms. In 1973 shipboard measurements during the Mid-Ocean Dynamics Experiment (MODE) revealed that the cold plumes resulted from southward advection of the surface water on the eastern flank of the MODE eddy and the warm plumes were a result of northward advection on the western side.Along the edges of the plumes, small-scale frontogenesis was observed but not resolved by the sampling scheme. Detailed measurements were made in March 1977 of the frontal structure at the southern end of a cold plume. These revealed the presence of smaller-scale motions with wavelengths of the order of 50 kms. Temporal evolution of surface features in the vicinity and along the front occurred extremely rapidly and was barely resolved by surveys spaced three to five days apart.

Published in: *Journal of Geophysical Research 83: 4589-4592, 1978.*

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

TECHNICAL REPORTS

BIBLIOGRAPHY(1) *AND INVERSE ANALYSIS OF THE TRIMOORED INTERNAL WAVE EXPERIMENT (IWEX)*(2)

(1) Melbourne G. Briscoe and Terrence M. Joyce

(2) Jurgen Willebrand, Peter Müller and Dirk J. Olbers

(1) The papers, reports, and un-refereed notes that have been published over the five-year period 1973-1977 on the Internal Wave Experiment (IWEX) or using data from IWEX are included in the bibliography. A journal article on the inverse analysis (based on the report that is bound as part of this Woods Hole Oceanographic Institution Technical Report) appeared in 1978 in *Journal of Geophysical Research, 83: 479-500,* authored by Muller, Olbers, and Willebrand.

Prepared for: *Applied Physics Laboratory of The Johns Hopkins University under Contracts 372111 and 372115, and for Office of Naval Research under Contracts N00014-74-C-0262;NR 083-004 and N00014-76-C-0197;NR 083-400.*

(2) This report described the inverse analysis of the IWEX data. The analysis is entirely confined to the spectral data in the internal wave frequency band averaged over the entire duration of the experiment.

The IWEX experiment has been described by Briscoe (1975). A brief summary and some supplements can be found in Part (I) of this report. The algebra and methods used for the analysis are given in part (II) and (III), the results are described in part (IV) and (V).The individual parts can be read separately. Volume (II) contains the tables and figures.

A summary of this report will be published in the Journal of Geophysical Research ('The IWEX-Spectrum' by P.Müller,D.J.Olbers and J. Willebrand).

Prepared for: *Applied Physics Laboratory of The Johns Hopkins University under Contracts 372111 and 372115, and for the Office of Naval Research under Contracts N00014-74-C-0262;NR o83-004 and N00014-76-C-0197;NR 083-400.*

CTD (CONDUCTIVITY, TEMPERATURE, DENSITY) OBSERVATIONS IN THE WESTERN MEDITERRANEAN SEA DURING CRUISE 118, LEG 2 OF R/V CHAIN, *FEBRUARY, 1975*

Harry L. Bryden, Robert C. Millard and David L. Porter

Eighty-two CTD stations were taken in the Mediterranean Sea during February, 1975. These stations were concentrated in the Alboran Sea near Gibraltar to investigate whether water typical of the deep western Mediterranean was flowing directly up and over the sill at Gibraltar. Temperature, salinity, and potential temperature at standard pressure are presented for each of the stations.

Prepared for: *NSF Grants OCE76-10940 and OCE74-19782 A03 and for the National Oceanographic Data Center under NOAA Purchase Order 6-19641.*

PERFORMANCE OF AN ABSOLUTE VELOCITY PROFILER BASED ON ACOUSTIC DOPPLER AND ELECTRO-MAGNETIC PRINCIPLES

John H. Dunlap, Thomas B. Sanford, and Robert G. Drever

This report describes the performance of a freely-falling velocity profiler called the Absolute Velocity Profiler (AVP). The AVP is distinguishable from our previously developed velocity profiler the Electro-Magnetic Velocity Profiler (EMVP) in that acoustic Doppler measurements are used to determine the reference velocity for the EMVP profiles. The AVP contains the essential measurements of the motional electric currents in the sea as implemented in the EMVP and in addition, collects acoustic Doppler measurements of frequency-shifted bottom echoes. The former measurements yield a profile of the horizontal components of velocity relative to a reference velocity, independent of depth, while the latter measurements determine the absolute velocity of the AVP vehicle with respect to the sea floor. The EM profile is obtained from the sea surface to bottom, and the acoustic Doppler measurements are made within about 300 m of the sea floor. The combination of the EM and acoustic Doppler measurements yields an absolute velocity profile throughout the water column. Performance analyses included in this report set method uncertainties of between 1 and 2 cm/s r.m.s. Measurements of temperature and its gradient are also made.

Prepared for: *NSF, Office of IDOE under Grant OCE76-24605.*

HYDROGRAPHIC STATION DATA OBTAINED IN THE VICINITY OF GEORGES BANK, MAY AND AUGUST, 1978

Richard Limeburner, John A. Vermersch, and Robert C. Beardsley

Two extended cruises were made during May and August, 1976, to measure the regional hydrographic structure in the vicinity of Georges Bank on the New England Continental Shelf. A summary of the hydrographic observations made during Cruise E2876 on the R/V *EASTWARD*and Leg 3 of Cruise 13 on the R/V *OCEANUS* are presented in graphic form.

Prepared for: *U.S.Geological Survey under Contract No.14-08-0001-15615 and for NSF Grant OCE76-01813.*

AUTO AND CROSS-BISPECTRAL ANALYSIS OF SCALAR AND VECTOR TIME SERIES: PROGRAMS, PROGRAM DESCRIPTIONS, AND TESTS WITH ARTIFICIAL DATA

Gerald H. Martineau and Melbourne G. Briscoe

This report describes a series of computer programs developed at Woods Hole Oceanographic Institution during 1977 to compute scalar bispectra and cross-bisectra (BISCAL), rotary bispectra and cross-rotary bispectra (BIVEC) and to display corresponding bicoherences (BPLOT) and rotary bicoherences (RBPLOT) as contour plots on the bi-frequency plane.The usual method of calculating the bispectrum in the frequency domain after using the Fast Fourier Transform is used here, and so there is a program for calculating the Fourier coefficients (FOURIER) as well as programs for organizing the data (FRAGTAP, ORDAT) or generating artificial series (GENTRAN) if desired. There is also one special-purpose program which calculates line integrals of (scalar) bicoherences in the bifrequency plane along paths of constant $\omega_3 = \pm \omega_1 \pm \omega_2$ to determine the relative total contribution of quadratic interactions to each frequency (BISUM). After the descriptions of these programs, there is a collection of actual FORTRAN-IV listings of them arrnaged alphabetically.

Prepared for: *NSF under Grant OCE76-14739.*

BISPECTRA OF INTERNAL WAVES

C. Henry McComas, III

Derived from the equations of motion, the bispectrum of power indicates the rate of enerby transfer among components of the internal wave field. This, or any other bispectrum, can be evaluated from weak resonant interaction theory given the wave spectrum. Using the Garrett and Munk model of the deep open ocean internal wave spectrum, the bispectrum of power and the closely related auto-bispectrum of vertical displacements are evaluated numerically with the intention of providing an observational test of the weak interaction theory and its predictions. The resulting levels of the bispectra for typical deep ocean internal waves are generally too low to be observed with any statistical confidence in an experiment of reasonable length and cost.

Prepared for: *NSF under Grant OCE76-23532 and in part by Grant OCE77-25803.*

A DIGITAL TAPE FORMAT FOR WOODS HOLE OCEANOGRAPHIC INSTITUTION CTD DATA

Robert C. Millard, Anselm Blumer and Nancy Galbraith

A new digital data tape format has been developed to be used for data from the WHOI/ Brown CTD microprofiler. CTD-78 Version 1 as detailed in this report is designed as a flexible and expandable internal data format adapted to the Hewlett-Packard 2100/21MX series 16-bit mini-computers currently used to transcribe and process CTD data at sea. The ten record types presently used in thie multifile tape format store CTD and associated water sample data and the labeling information needed to convert the data to physical units. Record types are identified by unique keywords.

Prepared for: *ONR under Contract N00014-76-C-0197;NR 083-100.*

RANGES AND EXTREMES OF THE NATURAL ENVIRONMENT IN AND ABOUT THE HAWAIIAN ARCHIPELAGO RELATED TO DESIGN CRITERIA FOR OCEAN THERMAL ENERGY CONVERSION PLANTS

Arthur R. Miller

Examination of data from the water areas surrounding the Hawaiian Islands leads to the conclusion that Hawaii is suitably situated for ocean thermal energy conversion. Historical records of surface temperature for the Hawaiian area and the tropical and subtropical Pacific suggest that the proposed site may be vulnerable to significant epochal changes and yearly shifts in base temperatures but the site should still remain within the limits of operational parameters. Annual and monthly charts have been prepared for sea surface temperature, surface wind speeds and directions, and reported storm severities.

Prepared for: *Department of Energy, Division of Solar Energy under Contract No.EG-77-S-02-4293.A000.*

A COMPILATION OF MOORED CURRENT DATA AND ASSOCIATED OBSERVATIONS (MODE-SITE, VOL.XVI 1971-1975)

Susan Tarbell and Ann Spencer

Current, temperature and pressure measurements from instruments moored in the MODE area during the years 1971-1975 are presented. Record lengths vary from two weeks to seven months. Data from individual instruments are displayed in the form of statistical tables, spectral plots and variables vs. time plots. Current data are additionally displayed as progressive vector plots. Composite plots of temperature, pressure or velocity are included for groups of records which could be combined to show a meaningful spatial or temporal array. Selected CTD data are included and displayed as potential temperature and salinity versus pressure.

Prepared for: *ONR Contracts N00014-66-C-0241;NR 083-004; N00014-74-C-0262;NR 083-004; and N00014-76-C-0197;NR 083-400 and the NSF, Office for IDOE, Grants GX 29054 and OCE75-03962.*

A COMPILATION OF MOORED CURRENT METER DATA AND ASSOCIATED OCEANOGRAPHIC OBSERVATIONS. VOL.XVII (POLYMODE ARRAY II DATA)

Susan Tarbell, Ann Spencer and Richard E. Payne

Summaries of observations from moored stations and CTD profiles taken during POLYMODE Array II are presented. Data series of 27 months duration at 12 locations were achieved with three consecutive deployments. Current meters were set at nominal depths of 600, 1000, 1500 and 4000 meters at eight of the locations and at 4000 meters at the remainder. Nine data series of eight months duration were obtained at similar depth at three additional locations.

Low passed east and north current components, temperature and pressure from current meters and temperature/pressure recorders are displayed graphically and in tabular form. Spectral diagrams are plotted for temperature and the vector components when a continuous two-year time series was achieved.Progressive vector plots are included for velocity data.

Selected CTD data are presented as potential temperature and salinity values plotted against pressure.

Prepared for: *ONR Contract N00014-74-C-0262;NR 083-004; N00014-76-C-0197; NR 083-400 and for NSF under Grant OCE75-03962.*

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 #04-6-158-44104 and #04-8-MO1-149.*

Additional sources of support for specific papers are noted where appropriate.

PRIMARY IMPACTS OF GROWING AQUATIC PLANTS FOR ENERGY

Thomas Hruby

All systems proposed for the large-scale culture of algae or aquatic plants will affect the natural and the human environment to some degree. On the open ocean potential hazards include the leachates from the synthetic lines used to support plants, toxic exudates from seaweeds, the creation of fog over upwelled cold water, and the entrainment of mesopelagic animals in the upwelling pipe. Near shore these problems are compounded by potential conflicts with a wide variety of other human activities. However, the impacts of growing aquatic plants can be minimized if fully closed pond culture systems are built in marginal lands.

Published in: *Proceedings of the American Nuclear Society - "Conference on Environmental Aspects of Non-conventional Energy Resources-II", Sept. 26-29, 1978, Denver, Colorado.*

IMPACTS OF LARGE-SCALE ALGAL BIOMASS SYSTEMS

Thomas Hruby

Any activity undertaken by man on a scale as large as that proposed for the production of fuel from plant biomass carries with it the possibilities of a serious upset in the earth's environment. The farming of algae is no exception, and adverse environmental impacts will to some degree be unavoidable. In view of the present legal requirements and the general concern for our environment, the possible impacts of a system may be critical in determining the final choice of design. By understanding the dangers posed by different systems, long and costly delays may be avoided in developing this new energy resource.

Although specific impacts can be quantified only after a design and location have been chosen, it is possible, at this stage in the planning process, to determine the areas where dangers exist and where additional research is needed. Only the primary impacts will be considered in this report. However, it should be remembered that developing any industry on the scale proposed will have a profound influence on the social and economic fabric of the nation; together with additional environmental effects resulting from the subsidiary industries that will be stimulated.

Several different, and rather complex, systems are being considered for the open ocean, coastal and land environments. However, these share some of the same subsystems, and to avoid duplication, the environmental impacts of algal biomass production will be considered in terms of these subsystems. The impacts, as presented in Table 1, were evaluated on the basis of presently available information. However, many of the predicted impacts can only be considered as hypotheses since the basic scientific information necessary for accurate estimates of environmental dangers is often lacking.

WHOI REFERENCE NO. 78-31. Published in: *"Cost Analysis of Algal Biomass Systems", summer, 1978.*

SALT MARSH NITROGEN FLOW ANALYSIS: FERTILIZATION AND THE ALLOCATION OF BIOLOGICAL PRODUCTIVITY

Thomas M. Leschine

A five-compartment schematic model of the flow of nitrogen through Great Sippewissett Marsh is presented. Flows are described in terms of annual inputs, outputs and intercompartmental transfers of nitrogen. The nitrogen in all forms occurring in the marsh is considered, though dissolved organic nitrogen is disaggregated from the total flow.

A computer-aided input-output analysis is performed on the model to assess the degree to which nitrogen inputs to the marsh surface are linked to nitrogen outputs in the form of net growth in marsh shellfish. In this way the effects of both direct and indirect flows linking the two compartments involved are considered. The analysis is done to assess the likelihood that a large-scale application of fertilizer to the marsh surface will significantly enhance shellfish growth in marsh tidal creeks. While no definitive answer to this question can be given, it is argued that the present level of understanding of the marsh nitrogen cycle does not support an expectation that shellfish growth will be enhanced. This argument is supported by a comparative analysis which shows a strong likelihood that *Spartina* growth is enhanced by fertilization, an effect which has been observed already.

INPUT-OUTPUT ANALYSIS FOR SALT MARSH BIOPRODUCTIVITY

Thomas M. Leschine and Leah J. Smith

Input-output analysis is applied to a salt marsh system to describe possible bioeconomic effects of adding nitrogen fertilizer. A simple model is developed to trace exchanges of nitrogen among five compartments of the marsh model: sediments, *Spartina* root/rhizome biomass, *Spartina* aboveground biomass, tidal water and shellfish. The resulting matrix can be used to show relationships in the system among controllable inputs and outputs with potential economic value. Some costs of fertilizing an experimental plot are given,

but no direct comparison can yet be made between costs and likely economic benefits.

Published in: *MTS/IEEE Oceans 1978 Proceedings, 285-293.*

WHAT'S HAPPENING AT THE FISH PIER

Margaret Linskey

This article presents a brief history and description of the Boston Fish Pier. It discusses socioeconomic factors affecting the drastic decline in the Boston Fish business and progress of the Massport-directed pier renovation. The Fishery Conservation and Management Act of 1976 was instituted to address the foreign over-fishing problem and to conserve the fish stocks for domestic exploitation. If managed properly by the Regional Fishery Management Councils and with industry cooperation, it is hoped that the stocks will rejuvenate within five years. Progress in market development of less popular species is essential. Increased fish stocks, decrease in foreigh fishing effort and the government and Masport vessel loans provide incentives for fishermen to build new vessels and improve old ones. Not only is it historically appropriate to preserve the pier; the renovation will also provide long-term employment and the means to revive the Boston Fish Pier as a flourishing fishing port.

Published in: *Aquasphere (Journal of the New England Aquarium), 12(2), October 1978.*

THE GROWTH OF AQUACULTURE IN DEVELOPING COUNTRIES: POTENTIALS, PATTERNS, AND PITFALLS

Yoshiaki Matsuda

The expectations for advances in aquaculture throughout the world have not taken into account the constraints of human abilities. Sustained aquaculture development depends on three essential components: basic conditions (supply and demand, environmental suitability, technical capability, legality, experience, and quality of leadership); infrastructure; and short-term economic feasibility. Until the industry reaches the "take-off" stage, the growth of aquaculture is a slow, step-by-step process. Elimination of any one of the limiting factors will contribute somewhat to this growth, but not much. Nevertheless, the best way to develop aquaculture is to eliminate the limiting factors one by one.

Published in: *Fisheries, 3(4), July-August, 1978.*

IMPLICATIONS OF THE JAPANESE EXPERIENCE IN AQUACULTURE DEVELOPMENT FOR THIRTY-THREE FOOD-SHORT COUNTRIES

Yoshiaki Matsuda

Aquaculture development in Japan has been limited by the following factors: supply and demand, environmental suitability, technical capability, legality, experience, infrastructure, existence of leadership, economic feasibility and social welfare incentives. Similar limiting factors were examined for thirty-three food-short countries. Fifty-five aquaculture variables were tested using multiple regression analysis combined with Pearson correlation analysis. Results imply that aquaculture development in these countries is affected by the same limiting factors as in Japan. These findings are the basis for a two-dimensional aquaculture development model which may be helpful in coping with future technology transfer problems.

Published in: *MTS/IEEE '78 Proceedings, 188-198.*

FACTORS LIMITING THE DEVELOPMENT OF AQUACULTURE: JAPANESE EXPERIENCE

Yoshiaki Matsuda

The purpose of this study is to provide an understanding of those factors which have limited the development of Japanese aquaculture in the hope that it would have some applications to the problems of aquaculture in developing countries. In order to achieve this purpose, the history of aquaculture in Japan is reviewed from chronological, geographical, species and institutional points of view. Conclusions reached in this study reveal that throughout the history of Japan, aquaculture development has been limited by supply and demand, environmental suitability, technical capability, legality, experience, infrastructure, existence of leadership, economic feasibility and social welfare incentives. Supply and demand, environmental suitability, technical capability, legality and experience become crucial as basic limiting factors for aquaculture development only when leadership exists, and infrastructure, economic feasibility and social welfare incentives are sound and adequate. Unlike conventional coastal fisheries, aquaculture is an industry which demands more rational management. The most important factor is the existence of leadership which coordinates supply and demand, environmental suitability, technical capability, legality, experience, infrastructure and social welfare incentives with economic feasibility. The development of aquaculture depends on simultaneous development of all these factors, not on the preponderance

of any one factor. Within the framework of this generalization, issues pertaining to aquaculture development in developing countries could be handled by specialization process.

SHRIMP THAT SLEPT: HOW MEXICO UNDERDEVELOPED ITS RURAL PACIFIC FISHERIES

James R. McGoodwin

The development of shrimp-export industry in Pacific Mexico has brought about the underdevelopment of that region's rural coastal fisheries. The rural fishery of south Sinaloa provides a case in point. The developmental sequence examined here provides a point of departure for more general considerations of fisheries management and development in the lesser-developed countries.

PELAGIC SHARK FISHING: A CONTEXT FOR COOPERATIVE ACTION

James R. McGoodwin

Adaptability and fluidity with regard to cooperative action is observed among Mexican peasant fishermen who work in two radically different contexts: (1) a small, rural-coastal town, and (2) pelagic shark fishing. Their uncooperative behavior in the former context, and cooperative behavior in the latter, results mainly from how those opposed behavioral strategies are capable of reducing objective risks and uncertainties associated with essential economic activities.

Additional support: *E.D.Farmer International Fellowship Fund, Institute of Latin American Studies, The University of Texas at Austin, Texas.*

REMARKS ON AQUACULTURE POLICIES IN LATIN AMERICA

Francisco J. Palacio

The social dimension of aquaculture is the most important aspect in developing policies aimed at its implementation and optimization in Latin America (LA). On a broad scale, the potential for aquaculture in meeting alimentary needs is only limited and its greatest promise lies in providing supplemental proteins to the rural poor. This goal cannot be considered independently from policies leading to regionalization and self-sufficiency. The development of regional food production and its integration favor the adoption of labor-intensive and low-technology culture practices; capital-intensive and vertically integrated enterprises aimed mostly at export markets should be evaluated in terms of energy and infrastructure costs. These systems are subjected to the impact of several external factors, in which water quality and environmental conservation policies are of paramount importance and consequence; internal factors depend on a variety of market, resource, technical and social factors.

A review of early aquaculture progress in LA (FAO, 1976b), indicates failures and successes. The problems seem to lie on the diffusion of policy and implementation responsibilities. Lack of expertise and trained manpower has been identified as an important drawback in developing aquaculture in LA. It is argued that there are no identifiable obstacles to manpower development other than the lack of government commitments which passively place high reliance upon international assistance efforts, of limited catalytical potential, without stimulating indigenous excellence and opportunities for its extended expression. This difficulty is ascribed to the limited role of the sea and rivers in the LA culture.

Paper prepared for: *Seminar on "Aquaculture Policy Options for National and Corporate Planners".*

NEW ENGLAND FISHING, PROCESSING AND DISTRIBUTION

Susan B. Peterson and Leah J. Smith

The New England fishing industry is examined in terms of the capacity of the fishing fleet, of the processing plants, and of the transportation system. Limitations on the capacity of the industry, and its capability and flexibility, are explored in terms of social, economic and technical aspects. The study is based on interviews with fishermen, buyers, processors and distributors, and on data made available by the National Marine Fisheries Service. Although the fisheries is now in a state of expansion and both vessels and plants have a greater capacity than is now being used, the major problem that may restrict expansion in both fishing and processing are quality control, species selection and market development.

Principal support: *NOAA Contract #03-6-043-35165.*

OCS DRILLING MUD DISCHARGES: THE DEVELOPMENT OF ENVIRONMENTAL REGULATIONS

Alison Rieser and Judith Spiller

Drilling muds provide the first line of defense in blow-out prevention technology; however, concern exists over the effects of drilling mud discharges on the marine environment. Drilling mud typically contains barium

sulfate, ferrochrome lignosulfonate and biocides. Further, during use, muds mix with formation waters and cuttings often containing heavy metals. Thus, their discharge is potentially polluting, although degrees of solubility and levels of toxicity for their constituents have yet to be defined for the marine environment. In the absence of certainty of the effects of these materials, a regulatory program for their discharge into the Baltimore Canyon area of the Atlantic has been developed by Region II of EPA. The initial program, based on the Ocean Dumping Criteria established under the Marine Protection, Research and Sanctuaries Act and the effluent limitation guidelines developed under the Federal Water Pollution Control Act, was modified in response to information supplied by the oil industry permit applicants. Future limitations will be based on the results of a discharge monitoring program required under the final permits and designed by industry in consultation with EPA. The revised features of Region II's monitoring program involve identity of test species, periodicity of sampling and the sampling grid. This interplay of industry and a federal agency provides a case study of the compromises reached when there exists both a critical need to prevent environmental degradation and a strong pressure to exploit a resource in the context of a lack of information on the effects of our use of the marine environment.

Additional support: *American Petroleum Institute and NL Industries.*

CASE STUDIES IN ECONOMIC EFFECTS OF LIMITING ENTRY TO THE FISHERIES

Leah J. Smith

Fisheries management has grown more complex as man has evolved increasingly sophisticated methods for harvesting, preserving and distributing fish. Management techniques intended to conserve stocks of fish have included quotas and limitations on equipment. However, as overfishing has grown more common in spite of conservation attempts, an alternative management method, limiting entry to the fisheries, has been proposed. Limited entry denies access to the resource to specific individuals or groups in order to preserve the economic health of the industry. The economic effects of limited entry programs for commercial fisheries, in particular the effect of various forms of this management technique on industry structure, are detailed in this paper.

Discussion of the implications of limited entry for industry structure includes the following subjects: barriers to entry and exit, profitability, efficiency and innovation, allocation between fishermen and processors, and the degree of integration within the industry. The economic effects which have accompanied introduction of limited entry programs in several places are described here through case studies of Atlantic Canada, South Africa, Maine and Massachusetts. Concerns expressed over the introduction of limited entry programs to the fisheries of New England are examined and used to illustrate the problems of applying such techniques to U. S. fishery management.

Paper prepared for: *University of Washington Workshop on Limiting Entry to the Fisheries, May 1978.*

ANALYSIS OF METHODS FOR THE CULTURE OF Crassostrea virginica *IN NEW ENGLAND*

George C. Matthiessen and Leah J. Smith

Intensive use of the New England shoreline by competing interests severely limits the area available for shellfish culture. As a result, more recent production systems attempt to minimize the area required for culture while maximizing the likelihood of survival.

Various methods of culture tested during recent years are discussed, with specific reference to the American oyster (*Crassostrea virginica*). The technical and economic advantages and disadvantages of each of these methods are reviewed and compared.

In Press: *Proceedings of the World Mariculture Society, January 1979, Honolulu, Hawaii.*

Additional support: *Marine Research, Inc.*

THE 'PUBLIC FACE' OF THE NEW ENGLAND REGIONAL FISHERY COUNCIL: YEAR 1

M. Estellie Smith

The first year of the New England Regional Fisheries Management Council has been marked by its experimental aura. Neither the Council nor the various sectors (representatives of the Federal and State agencies, members of the fishing industry, the public at large) were clear as to exactly what they were to do and how they were to do it - except in the broadest, most flexible (ambiguous?) terms. This created certain operational difficulties, and confusion for those whose livelihood was affected by the Council's operation. This latter group, particularly the fishermen, knew little of what went on, save in terms of the 'public face' of the Council - i.e., that portion of the Council's performance which occurred during the monthly meetings which were open to the public and which, supposedly, received public input at that time.

This study defines that public face, deliberately avoiding the presentation of any data which was not accessible to the average audience participant, in an attempt to present some of the behavior which all participants demonstrated, and which generated responses and reactions on the part of the other sectors. It uses standard anthropological techniques of data gathering and analysis to show the degree to which impression management on the part of all the actors operated in a systematic fashion to produce action, reaction, and counter-action. Particularly emphasized is the communication aspects.

WHOI Reference No. 78-36.

Additional support: *Sabbatical funding from the State University of New York.*

TRANSGRESSION, REGRESSION AND EVOLUTION

Judith Spiller

Transgressions and regressions alternately open and close habitats for marine organisms; yet, their effect on diversifying lineages remains subject to speculation (Moore, 1955; Newell, 1962; Kauffman, 1970; Valentine, 1973; Boucot, 1975). In order to test their influence, two conditions must be met: a lineage must be undergoing diversification during one of these cycles and a fairly complete sedimentary cycle must be preserved. Two studies (Kauffman, 1970 and Spiller, in prep.) fulfill these conditions though they reach opposite conclusions. They do, though, provide quantitative evidence that transgressive cycles are correlated with evolutionary events.

GRADUATE STUDENTS

GRADUATE STUDENTS

Abstracts of papers and theses submitted in 1978 by graduate students of the Woods Hole Oceanographic Institution Doctoral Degree Program and the Massachusetts Institute of Technology/Woods Hole Oceanographic Institution Joint Program in Oceanography/Oceanographic engineering. Other papers authored or co-authored by graduate students are included in the departmental sections. Students are indicated by an asterisk in the Author Index.

THE CRUSTAL STRUCTURE AND SUBSIDENCE HISTORY OF ASEISMIC RIDGES AND MID-PLATE ISLAND CHAINS

Robert Sherman Detrick, Jr.

Submitted to the Woods Hole Oceanographic Institution-Massachusetts Institute of Technology Joint Program in Oceanography on May 5, 1978 in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Abstract

This thesis consists of three papers examining problems related to the crustal structure, isostasy and subsidence history of aseismic ridges and mid-plate island chains. Analysis of gravity and bathymetry data across the Ninetyeast and eastern Walvis Ridges indicates these features are locally compensated by an overthickening of the oceanic crust. Maximum crustal thicknesses are 15-30 km. The western Walvis Ridge is also compensated by crustal thickening; however, the isostasy of this part of the ridge is best explained by a plate model of compensation with elastic plate thicknesses of 5-8 km. These results are consistent with the formation of the Ninetyeast and Walvis Ridges near spreading centers on young lithosphere with flexural rigidities at least an order of magnitude less than those typically determined from flexural studies in older parts of the ocean basins. As the lithosphere cools and thickens, its rigidity increases, explaining the differences in isostasy between aseismic ridges and mid-plate island chains. The long-term subsidence of aseismic ridges and island/seamount chains can also be explained entirely by lithospheric cooling. Aseismic ridges form near ridge crests and subside at nearly the same rate as normal oceanic crust. Mid-plate island chains subside at slower rates because they are built on older crust. However, some island chains have subsided faster than expected based on the age of the surrounding sea floow, probably because of lithospheric thinning over mid-plate hot spots, like Hawaii. This lithospheric thinning model has major implications both for lithospheric and mantle convection studies as well as the origin of continental rift systems.

Supported by: *ONR Contract N00014-74-C-0262;NR 083-004, NSF Grants OCE 77-07941 and OCE 74-02636, and Woods Hole Oceanographic Institution's Education Office.*

SEASONAL OSCILLATIONS IN A MID-LATITUDE OCEAN WITH BARRIERS TO DEEP FLOW

Eric Firing

Submitted to the Joint Oceanographic Committee in the Earth Sciences, Massachusetts Intitute of Technology and Woods Hole Oceanographic Institution, on August 11, 1978, in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

Abstract

A two-layer linear analytic model is used to study the response of the mid-latitude ocean to the seasonal variation of the windstress. The most important component of the response is a barotropic quasi-steady Sverdrup balance.

A meridional ridge such as the Antilles Arc is modeled as an infinitely thin meridional barrier that blocks the lower layer but does not protrude into the upper layer. It is found that such a barrier has little effect on the upper layer flow across the barrier. This result is obtained provided the frequency of the motion is low enough so that free short Rossby waves are essentially nondivergent. In this case there is little coupling between the layers for energy propagating to the east away from the barrier.

A study of the dynamics of flow over a sloping bottom is made and the results are used to determine the effect on seasonal oscillations of eastern boundary slopes and triangular ridges. It is found that the presence of a slope at the eastern boundary has little effect. A meridional ridge that does not reach the interface may cause substantial scattering of free Rossby waves, but unless the ridge is steep its effect on the quasi-steady Sverdrup balance is minimal. However, if the ridge height is a substantial fraction of the lower layer depth and the width is comparable to the scale of free short Rossby waves, the ridge will tend to block flow in the lower layer, acting like the infinitely thin barrier. The theory suggests that the Anrilles Arc should have the effect of a thin barrier, while the Mid-Atlantic Ridge should have little effect on the response of the ocean to seasonal wind variations.

Supported by: *John and Fannie Hertz Foundation and by NSF Grant OCE 77-15600.*

NONLINEAR ENERGY AND ENSTROPHY TRANSFERS IN A REALISTICALLY STRATIFIED OCEAN

Lee-lueng Fu and Glenn R. Flierl

Abstract

We discuss the nonlinear transfers possible in a quasigeostrophic fluid with a basic stratification taken from oceanic data. The energy and enstrophy conservation laws imply a cascade of energy to lower total wavenumber (including both the horizontal wavenumber and the vertical mode eigenvalue). The triplet interactions among components with various horizontal wavenumbers and vertical structures, represented by the vertical mode numbers, are considered in detail for exchanges involving the barotropic and first three baroclinic modes. The transfer rates from one component into the other two are estimated and the most rapid transfers described as a function of the initial scale and mode number. These results show that barotropic motions will cascade to larger scale barotropic motions, first baroclinic small sacle motions will transfer to first baroclinic larger scales, and first baroclinic large scale motions will cascade to barotropic and first baroclinic motions at the deformation scale. Second and third mode motions prefer to transfer energy into small scale first and third baroclinic mode motions. We also show the relationship of these triplet interactions to Rossby wave instabilities and resonant triads. For the latter motions, the weakness of the nonlinearity adds additional constraints which imply that the motions will tend to become zonal.

Supported by: *NSF Grants DES 74-14356 and OCE 76-80210.*

FLUXES, DYNAMICS, AND CHEMISTRY OF PARTICULATES IN THE OCEAN

Wilford D. Gardner

Submitted to the Massachusetts Institute of Technology-Woods Hole Oceanographic Institution Joint Program in Oceanography on October 21, 1977, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Abstract

Sediment traps designed to yield quantitative data of particulate fluxes have been deployed and successfully recovered on four moorings in the deep sea. The traps were designed after extensive calibration of different shapes of containers. Further intercalibration of trap design was made in field experiments over a range of current velocities. Experiments with Niskin bottles showed that concentrations of suspended particulate matter obtained with standard filtration methods were low and had to be increased by an average factor of 1.5 to correct for particles settling below the sampling spigot.

The trap arrays were designed to sample the particulate fluxes both immediately above and within the nepheloid layer. The data derived from the traps have been used to estimate vertical fluxes of particles including, for the first time, an attempt to distinguish between the flux of material settling from the upper water column (the "primary flux") and material which has been resuspended from some region of the sea floor (resuspension flux). From these data and measurements of the net nepheloid standing crop of particles one can also estimate a residence time for particles resuspended in the nepheloid layer. This residence time appears to be on the order of days to weeks in the bottom 15 m of the water column and weeks to months in the bottom 100 m.

Between 80% and 90% of the particles collected in the six traps where particle size was measured were less than 63 μm. The mean size of particles collected in the nepheloid layer was about 20 μm, and above the nepheloid layer the mean was 11 μm.

Less than 3% of the organic carbon produced in the photic zone at the trap sites was collected as primary flux 500 m above the sea floor. The primary flux measured at two sites was enough to supply 75% on the upper Rise and 160% on the mid Rise of the organic carbon needed for respiration and for burial in the accumulating sediments.

From an intercomparison of the composition of particles falling rapidly (collected in traps), falling slowly or not at all (collected in water bottles), and resting on the sea floor (from a core top), it was determined that elements associated with biogenic matter, such as Ca, Sr, Cu, and I, were carried preferentially by the particles falling rapidly. Once the particles reached the bottom, the concentration of those elements was decreased through decomposition, respiration, or dissolution. Dissolution appears rapid in the vicinity of the sea floor, because despite an abundance of radiolarians, diatoms, and juvenile foraminifera collected in all traps, there forms were rare in core samples.

The dynamic nature of the nepheloid layer makes it possible for particles to be resuspended many times before they are finally buried. This enables sediment to be carried long distances from its origin.The recycling of particles near the sea floor may increase dissolution of silicious and carbonate matter.

Supported by: *ONR Contracts N00014-74-C-0262;NR 083-004 and N00014-75-C-0291 and M.I.T. Contract N00014-67-A-0204-0048.*

STUDIES OF DEEP-SEA SEDIMENTARY MICROTOPOGRAPHY IN THE NORTH ATLANTIC OCEAN

Roger Donald Flood

Submitted to the Massachusetts Institute of Technology-Woods Hole Oceanographic Institution Joint Program in Oceanography on January 20, 1978, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Abstract

Many of the small-scale topographic features (dimensions of centimeters to kilometers) found on the Blake-Bahama Outer Ridge (western North Atlantic, water depth greater than 4000 m) and in the Rockall Trough (northeastern North Atlantic, water depth greater than 2000 m) have been formed as bed forms of deep currents. These bed forms, all developed in cohesive sediments, include current ripples (spacings of tens of centimeters, formed transverse to the flow, longitudinal triangular ripples (spacings of meters, formed in sandy muds and parallel to the flow), furrows (spacings of tens to 100's of meters, formed parallel to the flow and presently either erosional or depositional), and regular sediment waves (spacings of a few kilometers, now found oblique to the flow and migrating either upstream or downstream). The local distribution of any given bed form is influenced by the presence of larger features. Bed forms are often found in zones which strike parallel to the regional contours.

Debris flows, affecting areas of 1000's to 10,000's of square kilometers, are also present in these areas. A debris flow studied in the Rockall Trough is erosional at its shallowest depth and depositional at greater depths. Gravitational flows strike perpendicular to the contours. Pockmarks (tens of meters in diameter, marking fluid seeps) are also found on the Blake-Bahama Outer Ridge.

The larger topographic features (greater than several meters) with steep slopes (greater than about 20°) can be observed on surface echo-sounding profiles either as fields of regular hyperbolic echoes (e.g., echoes from regularly-spaced furrows), fields of irregularly spaced, dissimilar hyperbolae (e.g., echoes from blocks, ridges, and folds in debris flows), or as regular features whose structure is often obscured by side echoes (e.g., echoes from sediment waves). Although near-bottom investigations are required to describe the features, the nature of the sea floor can often be inferred from the character of the echo-sounding profile. Similar echo-sounding records in different areas of the ocean indicate the presence of similar sea-floor features.

The morphology of the bed forms studied and the current and temperature structure of the overlying water column lead to conclusions about bed form origin and present-day interactions with deep currents.

Furrows form as erosional bed forms during high-velocity (>20? cm/sec) current events by large, helical secondary circulations in the bottom boundary layer. Once formed, furrows may develop into depositional features, or they may continue as erosional ones, depending on the local currents and the sediment supply.

Large, regular sediment waves may be formed at current speeds of 5 to 10 cm/sec by lee waves generated by topographic irregularities on the sea floor, such as submarine canyons, or by instabilities in the flow of deep, contour-following currents. Sediment waves develop where there is an abundant supply of sediment and steady mean currents. Waves appear to migrate upstream where tidal current fluctuations are smaller than the mean velocity, and downstream where they are larger. Near-bottom currents appear to be faster on the downstream side of upstream-migrating sediment waves than on their upstream side. The resulting variations in bed shear stress lead to higher sedimentation rates on the upstream side and bed form migration in that direction.

Supported by: *ONR Contract N00014-74-C-0262;NR 083-004 and NSF Grants DES 73-06657, OCE 76-22152 and OCE 74-01671.*

THE ENZYMATIC SYNTHESIS OF THE YELLOW PIGMENT, SEPIAPTERIN, IN Drosophila melanogaster

Gwen Grabowski Krivi

Submitted to the Massachusetts Institute of Technology/Woods Hole Oceanographic Institution Joint Program in Biological Oceanography in December, 1977, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

The enzyme system for the synthesis of the yellow pteridine pigment, sepiapterin (2-amino-4-hydroxy-6-lactoyl-7,8-dihydropteridine), from 2-amino-4-hydroxy-6-(D-*erythro*-1',2',3'-trihydroxypropyl) 7,8-dihydropteridine triphosphate (H_2-neopterin-PPP) has been found in extracts of *Drosophila melanogaster.*

The enzyme system has been purified approximately 50 fold from homogenates of the

heads of one- to three-day-old adult flies. During the purification procedure, two enzyme fractions of different molecular weights were identified as components of the enzyme system. Both fractions (enzyme A and enzyme B) are required for the enzymatic production of sepiapterin from H_2-neopterin-PPP. Enzyme A has a molecular weight of 82,000 and enzyme B of 36,000.

The pH optimum of the enzymatic reaction is 7.4 and the temperature optimum is 35°C. The Km for H_2-neopterin-PPP is about 0.01 mM. The reaction requires the presence of a divalent cation; Mg^{2+} is the most effective. The reaction also requires NADPH. The Km of the purified enzyme system for NADPH is about 0.07 mM. No sepiapterin is produced when H_2-neopterin or GTP is supplied as substrate in place of H_2-neopterin-PPP.

Of several unconjugated pterins that inhibit the enzymatic synthesis of sepiapterin from H_2-neopterin-PPP, sepiapterin and biopterin are the most effective inhibitors; pterin and D-*erythro*-neopterin are somewhat inhibitory; but xanthopterin, pterin-6-COOH, and isoxanthopterin are poor inhibitors. A discussion of the possible metabolic importance of this inhibition by unconjugated pterins is presented.

Tritium is incorporated from (3'-^{3}H)H_2-neopterin-PPP into sepiapterin in the presence of the purified enzyme system. Tritium is also incorporated into sepiapterin when the purified enzyme system is incubated with H_2-neopterin-PPP and pro-R NADPT. A discussion of two possible mechanisms for the enzymatic transformation of H_2-neopterin-PPP into sepiapterin is presented.

An analysis of the enzyme system which is responsible for the synthesis of sepiapterin during development has revealed the presence of a small peak of activity in extracts of eggs and first instar larvae and a larger peak of activity that appears at about the time of eclosion. Enzyme activity declines slowly as the fly ages. A significant amount of activity appears at all stages tested except the early pupae. Analysis for the production of sepiapterin has indicated that the peak activity which occurs in eggs and early larvae precedes the accumulation of sepiapterin in the larvae and that the larger peak coincides with the accumulation of sepiapterin in pharate and newly enclosed adults.

Analyses of a variety of eye-color mutants of *Drosophila melanocaster* have shown that the mutants *se*, ry^8, *v;bw*, and su^2-*s v;bw* all contain sepiapterin synthesizing activity equal approximately to the amount found in wild type flies. The specific activity of the enzyme system in extracts of *w/w* flies is 70% of that of the system in extracts of wild type flies. The mutants *pr* and pr^{bw} have only 15% as much enzyme activity for the synthesis of sepiapterin as do wild type flies. The addition of purified enzyme A to extracts of *pr* or pr^{bw} flies restores the sepiapterin synthesizing activity almost to the level found in wild type extracts. The addition of purified enzyme B to extracts of *pr* flies does not change the amount of sepiapterin synthesizing activity of these extracts.

Supported by: *NIH Contracts NIH-2-RO1-AMO3442-19 and NIH-GM-07-287 and NSF Grant NSF-7519513-PCM.*

ATTENUATION OF LOW ORDER MODES IN LOSSY ACOUSTIC WAVEGUIDES

H. David Leslie

Submitted to the Department of Ocean Engineering on September 1, 1978 in partial fulfillment of the requirements for the degree of Ocean Engineer and Master of Science in Ocean Engineering.

Abstract

Acoustic propagation is treated for sound sources in an ocean bounded from below by stratified layering. The bounding layers of the waveguide may be homogeneous-isovelocity or inhomogeneous with vertical sound speed gradients. The layers may be dissipative or nondissipative. The acoustic field is described with a normal mode expansion and modal attenuation coefficients are calculated for low order modes as a function of mode number and either frequency or phase velocity. The theoretical basis of the calculations is presented for multilayer isovelocity guides and for multilayer guides with index of refraction squared varying linearly with depth. Numerical results are presented for the Pekeris model of a fluid layer over a dissipative fluid halfspace. A compasison is made between various attenuation coefficients proposed in the literature.

Supported by: *ONR Contract N00014-75-C-0852.*

INVESTIGATIONS INTO THE SEASONAL DEEP CHLOROPHYLL MAXIMUM IN THE WESTERN NORTH ATLANTIC, AND ITS POSSIBLE SIGNIFICANCE TO REGIONAL FOOD CHAIN RELATIONSHIPS

Peter B. Ortner

Submitted to the Department of Biology of the Woods Hole Oceanographic Institution, October 1977, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Abstract

In many marine environments accumulations of chlorophyll have been reported to occur at or below depths to which 1% of ambient light penetrates. The phenomenon has been called the Deep Chlorophyll Maximum (DCM). On occasion zooplankton have been observed to be suggestively associated with a DCM. In order to determine, to what extent and under what circumstances, the DCM represents a significant food resource, data were obtained from vertically stratified net tows (both 0.333 μm and 0.067 μm mesh) and water bottle casts taken on eight cruises in the western North Atlantic between November 1973 and August 1976. Parameters measured included: zooplankton biomass, zooplankton functional group abundance, phytoplankton species abundance, chlorophyll concentration, ATP concentration, particulate nitrogen concentration, ^{14}C fixation, biological macro-nutrients (NO_3, NO_2, NH_3, PO_4, $Si(OH)_4$, oxygen concentration, temperature, and salinity. Parameters were measured as concommitantly as possible. Sampling was conducted in the Sargasso Sea, in Gulf Stream cold core rings, and in the Slope Water. Results obtained bear upon three major ecological problems: (a) the evolution of the biological community in a Gulf Stream cold core ring; (b) the sense in which the Gulf Stream represents an ecological discontinuity; and (c) the significance of the DCM as a locus for trophic activity.

Zooplankton biomass in the upper 800 m of four Gulf Stream cold core rings significantly exceeded that in the Northern Sargasso Sea. The center of its vertical distribution was uniquely deep. Such a distribution may result in reduced ecological efficiency and increase the flow of organic matter to the deep sea. The phytoplankton assemblage of a cold core ring was significantly different from that of both the Slope Water and the Northern Sargasso Sea many months after ring formation. Certain species appeared to capitalize on some aspect of the ring environment and were especially numerous in ring samples.

Due the composition, distribution, and variability of its characteristic phytoplankton the Slope Water represented a herbivore habitat very different from that in either the Northern Sargasso Sea or a six-month-old cold core ring. Under highly stratified conditions the preceding contrast was maximal. No common species was found only on one or the other side of the Gulf Stream, yet the species could be sorted into groups that had maximal abundances either in the Slope Water or the Northern Sargasso Sea. These groups appeared to differ in their responsiveness to nutrient concentration variation.

The DCM in diverse environments appeared to be an essentially identical phenomenon. The DCM accumulated phytoplankton cells (and possibly other organic particulates) sinking from above. Phytoplankton growth occurred at DCM depths despite low light levels. Various microbial processes appeared to be enhanced at DCM depths. As a consequence the DCM signalled a depth zone which, under stratified conditions, was a significant food resource expecially since mixed-layer food was scarce.

Concentrations of zooplankton biomass at the DCM and the vertical distributions of zooplankton functional groups indicated the DCM in the western North Atlantic was a locus of particularly intense trophic activity. The depth interval of the DCM had more total biomass and more microplankton biomass than above and below. Further, at DCM depths, the abundance of particular zooplankton functional groups appeared to reflect the size of the dominant phytoplankton. Not only presumed herbivores but a purely carnivorous group, the chaetognaths, on some occasions aggregated at DCM depths.

Supported by: *ONR Contracts N00014-66-C-0241;NR 083-004; N00014-74-C-0262;NR 083-004 and NSF Grant DES74-02783A1.*

LENGTHS OF INTERMEDIATE AND DEEP SEISMIC ZONES AND TEMPERATURES IN THE DOWNGOING SLAB OF LITHOSPHERE

Peter Molnar, David Freedman, and John S.F. Shih

Abstract

If intermediate and deep earthquakes occur in the coldest portion of the downgoing slab, then the lengths of seismic zones should be approximately proportional to the product of the convergence rates and the square of the thickness of the lithosphere. The lengths are therefore approximately proportional to the product of the convergence rates times the age of the lithosphere. Although there is considerable scatter, observed lengths are approximately proportional to such products, and are not simply related to the rate, the age

or the thickness alone. Calculations of temperature at the depths of the deepest events suggest that the cut-off temperature increases from about 600 ± 100°C at 200 km to 830 ± 50°C at 650 km depth, but the cut-off potential temperature is approximately constant, (870 ± 100°K) at all depths. Estimates of temperatures at the depths of the deepest events are made for regions where the subduction rates or ages of the lithosphere are not known. For instance, we infer that the Philippine Sea and Pacific plates move slowly if at all with respect to one another. Also, we suspect that the Farallon plate was too young to be subducted to a great distance beneath Western North America in the Paleogene. Assuming that the strength is a thermally activated parameter and using the activation energy for olivine, a crude estimate of activation volume is obtained from this temperature dependence.

Supported by: *NSF EAR 7521848.*

THE VERTICAL FLUX OF PARTICULATE ORGANIC MATTER IN THE PERU COASTAL CURRENT AS MEASURED WITH A FREE-DRIFTING SEDIMENT TRAP

Nick Staresinic

Submitted to the Woods Hole Oceanographic Institution/Massachusetts Institute of Technology Joint Program in Biological Oceanography in partial fulfillment of the requirements for the Degree of Doctor of Philosophy, August, 1978.

Abstract

Measurements of the vertical flux of particulate organic matter in aquatic ecosystems have conventionally been made with moored sediment traps. *In situ* dye experiments conducted in Buzzards Bay, Massachusetts, suggest that the turbulent wake established over the entrance of such devices may severely bias the collection process, but that use of a free-drifting sediment trap effectively relieves this problem. The free-drifting mode also permits shallow deployments in deep water columns without the engineering restrictions accompanying deep moorings, and the monitoring of the development of particular water parcels, such as upwelling plumes.

An intercomparison of moored and free-drifting sediment traps of identical design was conducted off the coast of Peru in 1978. In each of three deployments to 30 m in a 120 m water column, the free-drifting sediment traps collected a greater amount of material. The quality of material in each type of trap also differed, material collected in the moored traps being of a consistently higher C/N ratio.

Free-drifting sediment traps were used during 1977 and 1978 in an investigation of the vertical flux of particulate organic matter in the Peru coastal upwelling. Work was concentrated near the upwelling center located near 15°S.

Traps set at 50 m in austral fall, 1972, collected an average of 237 mg C $m^{-2}day^{-1}$ and 24 mg N $m^{-2}day^{-1}$. The vertical flux of particulate organic carbon averaged about 9% of the daily primary production of carbon in the euphotic zone. Although phytodetritus dominated the material collected at some stations, fecal rods, believed to be derived from young fish, were the sole recognizable component at other stations.

In austral fall, 1978, pairs of free-drifting sediment traps were simultaneously deployed at the base of the euphotic zone and at 50 m. Mean daily flux of particulate organic carbon and nitrogen through the base of the euphotic zone was 533 mg C $m^{-2}day^{-1}$ and 86 mg N $m^{-2}day^{-1}$, respectively. Carbon flux was about 20% of the daily carbon primary production. The 50 m traps collected an average of 25% mg C $m^{-2}day^{-1}$, or about 10% of the daily primary production.

A diurnal variation in the vertical flux of bulk organics through the base of the euphotic zone was observed. Nocturnal carbon fluxes were as much as 50% greater than daytime fluxes. The increased pigment content and relatively low C/N ratio of the night material suggested an increased flux of phytodetritus.

Qualitatively, night samples were distinguished from day samples by the presence of the fresh molts of *Euphausia mucronata,* a vertical migrator, in the former. Molts sank at an average rate of about 150 m day^{-1}. Analysis of the molt data from a deep and shallow pair of night traps suggested that a larger fraction of the population molted in the upper 15 m of the water column.

Anchoveta fecal casts were a conspicuous component of the trap material collected at many stations. Fragments of fecal casts, with a mean dry weight of about 0.3 mg, contained about 6.5% carbon and 0.7% nitrogen. Sinking rates of fragments, up to 850 m day^{-1}, were comparable to the highest values reported for euphausiid fecal pellets and over five times greater than those measured for euphausiid molts. Owing to the vertical migration of anchoveta, casts were generally more abundant in night samples than in day samples.

The flux of particulate protein through the base of the euphotic zone averaged more than 900 mg protein $m^{-2}day^{-1}$ at a series of three day/night stations over the Peruvian

shelf. A diurnal trend in protein flux, similar to that found for organic carbon, was observed. On a dry-weight basis, particulate protein composed a larger fraction of the material in the shallow traps than in the deep traps (about 10% versus 5%). The mean protein:nitrogen ratio calculated for the sediment trap material, 9.9, was higher than the factor 6.25 commonly used to convert particulate organic nitrogen to protein.

It is concluded that the vertical flux of particulate matter is an important component of the organic matter cycle of the Peru coastal upwelling ecosystem.

Supported by: *NSF Predoctoral Dissertation Grant, the Tai-Ping Foundation and Woods Hole Oceanographic Institution.*

RESPONSE OF A PENDULUM SPAR TO 2-DIMENTIONAL RANDOM WAVES AND A UNIFORM CURRENT

George Rodenbusch

Submitted to the Deaprtment of Ocean Engineering in August 1978 in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

Abstract

A linearized theory for the response of a circular pendulum spar in 2-dimensional waves and a uniform current is developed. The linear forces on the cylinder are predicted using an approximate potential flow theory for slender bodies. The dynamic equations are then amended to account for the wake effects of viscous bluff body flow by including a quadratic drag law and neglecting wave damping. A spectral model for the forces on a cylinder due to an oscillating wake, modeling the force as a frequency modulation process, is proposed. The non-linear equations of motion which result are then solved, assuming constant force coefficients, by linearization for use with a Gaussian random sea. The method of equivalent linearization is extended to include mean flow effects and a spatially distributed process. Some numerical experiments are then used to test the performance of the linearization. For a variety of environments, the linearization predicts the standard deviation of the simulation response to within 10% and the mean angle of inclination to within 30%. Results of the numerical experiments indicate that there is significant variation (order of magnitude changes) in both response and mean angle of inclination. Thus, significant changes are followed by the linearization.

A laboratory experiment was carried out to test the linearized spar model in a realistic fluid environment. Only the low Keulegan Carpenter number regime was investigated. With some minimal manipulations, good agreement is obtained between the experiment and the linearized estimates. It appears that the drag coefficients for vortex induced in-line forces may be an order of magnitude larger than those reported in the literature, .5 instead of .06, and that the shedding of vortices due to steady flow may reduce the added mass coefficient significantly, as observed in oscillating flows with significant vortex shedding.

Supported by: *Office of Sea Grant Contract 04-6-158-44106; NSF Graduate Fellowship and Carl E. Menneken Fellowship for Scientific Research.*

A STUDY OF THE VELOCITY STRUCTURE IN A MARINE BOUNDARY LAYER - INSTRUMENTATION AND MEASUREMENTS

John Steven Tochko

Submitted to the Department of Ocean Engineering in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Abstract

The design and operation of a unique flow measuring instrument for bottom boundary layer studies in the marine environment is documented. The effectiveness of the instrument in acquiring data with which models of near bottom flows in the ocean can be tested is demonstrated by the results of a field experiment in Vineyard Sound.

The instrument uses four sensors which measure the mean and fluctuating parts of the three components of the velocity vector at four heights above the sea bed. The sensors employ the acoustic travel time difference technique, and are designed to minimize sensor-induced flow disturbances. BASS, an acronym for Benthic Acoustic Stress Sensor, has a resolution of .033 cm/sec per least bit, a range of ±62 cm/sec, noise of .07 cm/sec in 10 sec, and an estimated accuracy of ±.5 cm/sec, referred to an *in situ* zero point. A complete set of velocity measurements is made every .750 seconds, each measurement being the vector component averaged over 15 cm. The data is internally recorded on digital cassette tape. Eight hours of continuous data can be recorded.

BASS was deployed in a tidal flow in Vineyard Sound at a depth of 10 m where a time series of u, v, and w velocities at 26 cm, 46 cm, 96 cm, and 210 cm above the bottom was recorded. The mean velocity was determined by fitting each six-hour series with a sixth order polynomial and the deviations from the polynomial, the fluctuating velocity

components, were correlated to produce Reynolds stress profiles. The stress series shows very few negative stress events while the dominant positive events have an average duration of five seconds and exceed 30 dynes/cm^2.

Zero offset was removed from the mean by assuming a log profile at maximum ebb. Deviations from a log profile developed when the current dropped below 40% of maximum, i.e., when the flow could no longer be considered steady. A break in the Reynolds stress profile at 1 m suggested a larger length scale than the 1 cm bottom roughness was present in the flow. A value of u_* was determined by using the quadratic drag law (u_* = 1.56 cm/sec), the log profile method (u_* = 1.60 cm/sec), and the eddy correlation method (u_* = 1.91 cm/sec). Integral length scales of 5 m cross-stream, and 2.5 m vertically were identified by correlation calculations. Two length scales were present in the downstream direction, 5 m within 1 meter of the wall and 8 m further from the wall.

Supported by: *ONR Contract N00014-74-C-0262;NR 083-004 and NSF Grant OCE 76-10523.*

RATE ZONAL DENSITY GRADIENT ULTRACENTRIFUGATION ANALYSIS OF REPAIR OF RADIATION DAMAGE TO THE FOLDED CHROMOSOME OF Escherichia coli

Kevin Michael Ulmer

Submitted to the Joint Committee on Biological Oceanography of the Woods Hole Oceanographic Institution and the Massachusetts Institute of Technology, and the Department of Biology of the Massachusetts Institute of Technology on April 21, 1978, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Abstract

The structure of the membrane-free nucleoid *Escherichia coli* and of unfolding chromosomal DNA was investigated by sedimentation on neutral sucrose gradients after irradiation with ^{60}Co gamma-rays and ultraviolet light (254nm). Irradiation both *in vivo* and *in vitro* was used as a molecular probe of the constraints on DNA-pacaging in the bacterial chromosome. The extremely gentle lysis and unfolding procedures which were developed yielded undamaged, replicating genomes, thus permitting direct measurement of the formation and repair of DNA double-strand breaks at biologically-significant doses of ionizing radiation.

In vitro UV-irradiation of nucleoids resulted in an increase in the observed rate of sedimentation due to the formation of an unknown photo-product. In contrast, UV-irradiation of wild-ytype cells *in vivo* showed evidence of the formation of incision breaks which resulted in the relaxation of supercoiling in the nucleoid. Strand breakage was also observed following *in vivo* UV-irradiation of a *uvrB-5* strain, but at a lower rate and also accompanied by considerable unfolding of the chromosome. Such lesions may have been the result of direct photochemical reactions in the nucleoid, or enzyme activity associated with a *uvr*-indipendent mode of repair.

The number of domains of supercoiling was estimated at 170 per genome equivalent of DNA based on measurements of relaxation caused by single-strand break formation in *in vivo*- and *in vitro*-gamma-irradiated folded chromosomes. Similar estimates based on the target size of RNA molecules responsible for maintaining the compact packaging of the nucleoid predicted negligible unfolding due to the formation of RNA single-strand breaks at doses up to 10 Krad, and were bourne out by experimental measurements.

Unfolding of the nucleoid *in vitro* by limit-digestion with RNase or by heating at 70°C resulted in DNA complexes with sedimentation coefficients of 1030±59S and 625±15S respectively. The difference in these rates was apparently due to more complete deproteinization and thus less mass in the heated material. These structures are believed to represent intact, replicating genomes in the form of complex-theta structures containing 2-3 genome equivalents of DNA.

The rate of formation of double-strand breaks was determined from molecular weight measurements of thermally unfolded chromosomal DNA gamma-irradiated *in vitro*. Break formation was linear with dose up to 10 Krad, resulting in 0.27 double-strand breaks per kilorad per genome equivalent of DNA and requiring 1080 eV/double-strand break. The influence of possible non-linear DNA conformations of these calculations is discussed.

Repair of ionizing radiation damage to folded chromosomes was observed whthin 2-3 hours of post-irradiation incubation in growth medium. A model based on recombinational repair is proposed to explain the formation of 2200-2300S material during early stages of incubation and subsequent changes in the gradient profiles. Such behavior is not observed for post-irradiation incubation of wild-type cells in buffer or for a *recA-13* strain incubated in growth medium. Association of unrepaired DNA with Plasma membrane is proposed to explain the formation of a peak of rapidly sedimenting material (>>3100S) during the later stages of repair.

Direct evidence of repair of double-strand breaks during post-irradiation incubation in growth medium was obtained from gradient profiles of DNA from RNAse-digested chromosomes. The sedimentation coefficient of broken molecules was restored to the value of unirradiated DNA after 2-3 hours of incubation, and the fraction of the DNA repaired in this fashion was equal to the fraction of cells which survived at the same dose. An average of 2.7 double-strand breaks per genome per lethal event was observed, suggesting that 1-2 double-strand breaks per genome are rapairable in this strain of *E. coli*.

Supported by: *National Institute of Health Contract NIH 5 POI ES 0097; Grants ERDA EG-77-S-02-4198; DAAG 29-76-C-0034 and NSF National Needs Traineeship.*

HEAT FLOW IN THE WEDDELL SEA

Victor Zlotnicki, Ian O. Norton, John G. Sclater and R. P. VonHerzen

Abstract

Heat flow through the floor of the Weddell basin was measured between January and March, 1978, on board *ARA ISLAS ORCADAS*. The area is a difficult one, due to hard turbidites which bent many cores, and rough basement topography, which distorted the temperature field. The thirteen reliable stations show much higher heat fluxes than expected on the basis of cooling models for the lithosphere and the supposedly Jurassic age of the basin.

In Press: *Antarctic Journal of the United States.*

Supported by: *NSF Grant DPP 76-1905-A01.*

AUTHOR INDEX

	Page No.
Ahmed, Saiyed I.	C-6
Amirhor, Parviz	B-17
Anderson, Donald M.	B-14,B-15,B-18
Anderson, Michael	B-15
Armi, Laurence	PO-6
Aubert, Jane	GG-20
Aubry, Marie-Pierre	GG-22
*Austin, James A., Jr.	GG-5,GG-8
Bacon, Michael P.	C-22
Ballard, Robert D.	C-10;GG-16;OE-6
Bankston, Donald C.	C-9,C-12
Barr, Frank T.	GG-19
Baxter, Lincoln II	OE-3
Beardsley, Robert C.	PO-4,PO-5,PO-6,PO-9, PO-15
Behringer, David	PO-3
Belastock, Rebecca A.	B-18
Berggren, William A.	GG-19,GG-20,GG-22
Berteaux, Henri O.	OE-7
*Binder, Robert	B-13,B-14
Bischoff, James L.	C-13
Blakemore, Richard P.	B-10
Blumer, Anselm	PO-15
Bourg, Alain	B-20
Bowen, Vaughan T.	C-7,C-19,C-21
Bowker, Paul C.	B-22
Bradley, Albert M.	OE-7
Bradshaw, Alvin L.	PO-12
*Brand, Larry E.	B-12,B-18,B-19
*Bremer, Mary L.	GG-20
Brewer, Peter G.	C-18,C-22
Briscoe, Melbourne G.	B-23;PO-8,PO-14, PO-15
Briskin, Madeleine	GG-20
Bromund, Richard H.	C-3
Brooks, B. Ellwood	GG-24
*Brooks, James R.	B-26
Brown, Wendell S.	PO-5
Bryan, George M.	GG-14
Bryan, Wilfred B.	C-9,C-10,C-11,C-12; GG-3,GG-4,GG-8,GG-9,GG-10,GG-16
Bryden, Harry L.	PO-6,PO-12,PO-14
Burke, John C.	C-19
Burns, Kathryn	C-8
Butman, Bradford	OE-7
Cameron, Peter	GG-12,GG-23
Campbell, Ronald A.	B-8
Campenot, Robert B.	B-25
Cann, Joseph R.	GG-4
Capuzzo, Judith M.	B-15,B-22,B-23,B-24
Carey, Anne E.	C-21
Carr, Rosamund F.	C-14
Casso, Susan A.	C-19
Catchings, Rufus D.	GG-24
Cheney, Robert E.	PO-3,PO-4
Clarke, R. Allyn	PO-3
Clarke, W. Bryan	C-20
Clifford, C. Hovey	B-6
Comeau, Ronald	B-4
Cook, Peter J.	GG-12,GG-23
Corbett, Michael	B-14
Corwin, Nathaniel	17,B-22
Cox, James	B-24
Csanady, Gabriel T.	PO-3,PO-4,PO-12
Damuth, John E.	GG-11,GG-23
Davis, John D.	GG-19
Davis, Karleen	C-10
Dean, Jerome P., Jr.	C-6
de Boer, Jelle	C-10
DeBusk, Thomas A.	B-4
Deese, Patricia L.	B-22
Degens, Egon T.	C-17
De Long, Steve	C-10
Denham, Charles R.	GG-13,GG-14
Dennett, Mark R.	B-22
Deruelles, Josette J.	B-11
*Detrick, Robert Sherman	GG-16;GS-3
Deuser, Warner	C-8,C-17
Dick, Henry J.B.	C-10;GG-5,GG-6,GG-7,GG-16
Dickey, John S., Jr.	GG-10
Doherty, Kenneth W.	OE-10
Donnelly, Thomas W.	C-10,C-11
Dow, Willard	OE-3
Drever, Robert G.	PO-14
Dunlap, John H.	PO-14
Dunworth, James A.	GG-11
Elderfield, Henry	GG-18
Ellis, George R.	OE-3
Emery, Kenneth O.	C-10;GG-4,GG-9,GG-16, GG-19,GG-24
Everich, D.	B-13
Ewing. John I.	GG-i,GG-14,GG-15
Fainstein, Roberto	GG-8
Farrington, John W.	C-3,C-6,C-7,C-8
*Firing, Eric	GS-3
*Fitzgerald, Michael G.	GG-7
Fleer, Alan P.	C-18
Fleming, Henry S.	GG-16
Flierl, Glenn R.	GS-4
*Flood, Roger D.	GG-6,GG-7,GG-7,GG-11;GS-5
Flower, Martin F.M.	GG-3,GG-4,GG-9
Flowers, Kenneth D.	OE-3
Fox, Paul J.	C-10
Frankignoul, Claude	PO-7
Freedman, David	GS-7
Frey, Frederick A.	C-9,C-11,C-12;GG-9,GG-10
Frisk, George V.	OE-3,OE-4
*Fu, Lee-lueng	GS-4
Gagosian, Robert B.	C-3,C-5,C-6,C-16
Galbraith, Nancy	PO-15
Gamble, Eric	C-7
*Gardner, Wilford D.	GS-4
Gargett, Anne E.	PO-5
Gavini, Muralidhara B.	C-21
Gearing, Juanita N.	C-7
Gearing, Patrick J.	C-7
Georgi, Daniel T.	PO-8,PO-13
Giblin, Anne	B-20

*Graduate students in the Woods Hole Oceanographic Institution Doctoral Program or Massachusetts Institute of Technology/ Woods Hole Oceanographic Institution Joint Graduate Program.

AUTHOR INDEX

	Page No.
Giellis, George R.	OE-3
Glenn, Morris F.	GG-6,GG-14
Goldberg, Edward D.	C-7
Goldman, Joel C.	B-3,B-15,B-16,B-19
Grant, William D.	OE-8
Grassle, J. Frederick	OE-9
Greenbaum, Elias	B-16
Groman, Robert C.	GG-11
*Gschwend, Philip M.	C-3
Guillard, Robert R.L.	B-12,B-15,B-16, B-18,B-19
Gupta, Kishan C.	C-6
Haedrich, Richard L.	B-5,B-6,B-8
Halcomb, Robin T.	OE-6
Hall, Charles A.S.	B-20
Hamblin, Robert	C-6
Hammer, Paul M.	C-16
Hampson, George R.	B-20
Hanisak, M. Dennis	B-4
*Hao, Wei Min	C-18
Haq, Bilal U.	GG-22
Harbison, G. Richard	B-25
Harding, John M.	PO-9
Hardy, Edward P.	C-19
Harvey, George	C-7
Haury, Loren R.	B-23,B-26;PO-8
Hays, Earl E.	OE-1
Hayes, James M.	C-16
Hayward, Gary C.	OE-7
Heinzer, Franz	C-6
Heirtzler, James R.	GG-12,GG-17,GG-23
Hempton, Mark	C-10
*Henrichs, Susan M.	C-7
Herdman, Michael	B-9,B-11
Hess, Frederick R.	OE-4,OE-5
Hill, Harry W.	PO-3
Hoar, Peter G.	B-18
Hogg, Nelson G.	PO-4,PO-6
Holcomb, Robin T.	OE-6
Holland, Heinrich D.	C-14
Holland, William R.	PO-10,PO-11
Hollister, Charles D.	GG-6,GG-7,GG-11, GG-14,GG-15;OE-3
Honjo, Susumu	GG-19
Hosom, David S.	OE-7,OE-10
Houtz, Robert	GG-15
*Howarth, Robert	B-20,B-21
Hruby, Thomas	MP-3
Hulburt, Edward M.	B-16,B-17
Humphris, Susan E.	C-9,C-12
Hunt, John M.	C-3,C-4
Jacobson, Randell S.	GG-18
Jannasch, Holger W.	B-9,B-10,B-12
Janvier, Monique	B-9
Jenkins, William J.	C-16,C-20
Johnson, David A.	GG-11,GG-21,GG-23,GG-24
Johnson, James H.	B-7
Joyce , Terrence M.	PO-7,PO-9,PO-10,PO-14
Judkins, David C.	B-25
Kadar, Susan	C-18
Kallio, Peter E.	B-22
Kalmijn, Adrianus J.	B-9,B-10
Kaplan, Warren	B-21
Katz, Eli J.	PO-8,PO-13
Kenyon, Douglas E.	B-26
Kerfoot, William B.	B-22
Ketchum, Bostwick H.	B-22
Kieckhefer, R.M.	GG-18
Klein, George	GG-7
Koelsch, Donald E.	GG-13;OE-8
Kravitz. David	OE-9
Krefft, Gerhard	B-8
*Krivi, Gwen Grabowski	GS-5
Kuhnhold, W.W.	B-13
Kupferman, Stuart L.	C-20
Lake, J.	B-13
Lalezary, Shahla	B-17
Lancaster, Bruce A.	B-23, B-24
Lapointe, Brian E.	B-3
Ledbetter, Michael T.	GG-24
Lee, Cynthia L.	C-3,C-5
*Lee, Hsueh-tze	B-18
Lee, Richard F.	C-7
Leetmaa, Ants	PO-13
Leschine, Thomas M.	MP-3
*Leslie, M. David	GS-6
*Limeburner, Richard	PO-15
Linskey, Margaret	MP-4
Livingston, Hugh D.	C-19,C-20
Lonsdale, Peter	GG-6,GG-13,GG-15
Ludden, John N.	C-9,C-10;GG-9
Luyendyk, Bruce P.	GG-4
Luyten, James R.	PO-5
Madsen, Ole Secher	OE-8
Mahmoodian, Farideh	B-17
Maiefski, Romaine R.	B-7
Malcolm, Freida	C-10
Mandel, Manley	B-9
Manganini, Steven	B-22
Mangelsdorf, Paul C. Jr.	C-13
Mann, Alicja	B-22
Mann, Roger L.	B-3,B-4
Mantoura, Richard F.C.	C-6
Marcus, Nancy H.	B-5
Marquet, William M.	OE-7
Martin, Hugh B. III	B-7
Martin, John H.	C-7
Martineau, Gerard H.	PO-15
*Martinez, David R.	OE-4
Matsuda, Yoshiaki	MP-4
Matthiessen, George C.	MP-6
Mauzerall, David	B-16
Mavor, James W., Jr.	OE-6,OE-10
Maxwell, Arthur E.	GG-12
McAlister, Vicki	B-25
McCarthy, James J.	B-16,B-19
McCarty, Harry B.	C-7
McCave, Ian Nicholas	GG-7

Author Index

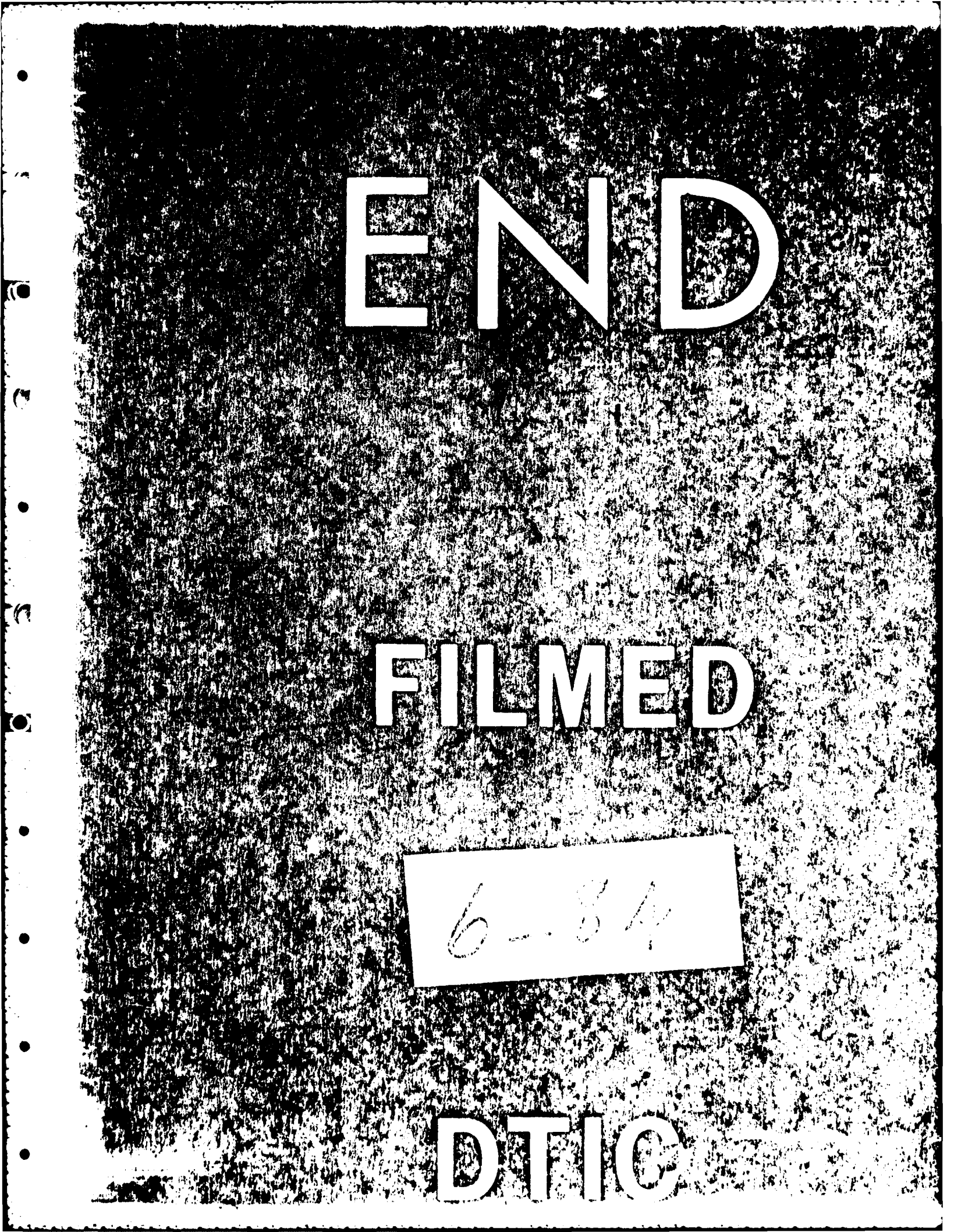
	Page No.
McComas, C. Henry, III	PO-15
McElroy, William D., Jr.	OE-7
McGoodwin, James R.	MP-5
Melson, William E.	C-10
Merrill, Arthur S.	GG-9,GG-19
Metcalf, Theodore G.	B-4
Michael, Peter	GG-8
Millard, Robert C.	PO-14,PO-15
Miller, Arthur R.	PO-15
Miller, Richard L.	C-6
Milliman, John D.	GG-7,GG-8,GG-21
Molnar, Peter	GS-7
Mooney, Robert	B-4
Moore, Berrien, III	B-20
Morel, Francois M.M.	B-15,B-18
Mottl, Michael J.	C-13,C-14,C-15
Moul, Edwin T.	B-20
Muller, Peter	PO-14
Munroe, Thomas A.	B-8
Murphy, Lynda S.	B-18
Nachum, Ronald	B-11
Nagasaka, Koichi	PO-3
Nealson, Kenneth H.	C-6
Melson, David M.	B-19
Nicotri, Mary E.	B-13
Nigrelli, Gale E.	C-5
Norton, Ian O.	GS-11
Officer, Charles B.	B-19
Olbers, Dirk J.	PO-14
Oppenheim, Alan V.	OE-4
Orr, Marshall H.	B-23;OE-4,OE-5;PO-8
Orren, Ann M	B-14
*Ortner, Peter B.	B-26;GS-7
Osborn, Thomas R.	PO-5
Owens, W. Brechner	PO-10
Packard, Theodore T.	C-6
Palacio, Francisco	MP-5
Palmer, Carl	B-22
Parker, Patrick L.	C-7
Parker, Robert	GG-13
Parmenter, Carol M.	GG-7
Payne, Richard E.	PO-16
Peal, Kenneth R.	OE-7,OE-8
Peavey, Dwight G.	G-16
Peters, Christopher S.	GG-21,GG-22
Peterson, Susan B.	MP-5
Phillips, Joseph D.	GG-16
Polloni, Pamela T.	B-5,B-6,B-8
Poore, Richard Z.	GG-5
Porter, David L.	PO-14
Porter, Robert P.	OE-5,OE-6
Powell, Thomas	GG-12
Price, Carl A.	B-19
Purdy, Graham M.	GG-13,GG-14,GG-15,GG-18
Quinby, Helen L.	B-15
Quinn, James G.	C-7
Rabinowitz, Philip D.	GG-13
Ramsdale, Dan J.	OE-3
Reardon, Ellen M.	B-19
Redfield, Alfred C.	B-22
Regier, Lloyd	PO-3
Reinhart, Kenneth L., Jr.	C-6
Reiniger, Robert F.	PO-3
Rhines, Peter B.	PO-7,PO-10,PO-11
Richardson, Philip L.	PO-3,PO-4
Rieser, Alison	MP-5
Rippka, Rosemarie	B-9,B-11
Risebrough, Robert W.	C-7
Robertson, Robert	B-6
Robertson, William	C-7
Robinson, Paul T.	C-10
*Rodenbusch, George	GS-9
Roeser, Hans R.	GG-12
*Rohr, Kristin	GG-15
Roman, Michael R.	B-19,B-20
Rose, Kenneth J.	B-9
Ross, David A.	GG-5,GG-14,GG-18,GG-25
Rowe, Gilbert T.	B-5,B-6
Ruddick Barry R.	PO-9
Rueter, John G.	B-18
Russell, Mary	B-17
Ryther, John H.	B-3,B-4,B-19
Salisbury, Matthew	C-11
Sanford, Thomas B.	PO-5,PO-14
Sassaman, Clay	B-6
Sato, Shunji	C-3
Saunders, Kim D.	PO-9
Sayles, Frederick L.	C-13
Schevill, William E.	B-7
Schmitz, William J.	PO-4
Schneider, Eric	C-7
Schouten, Hans	GG-14
Schowerer, John A.	OE-5
Schwarzenbach, Rene P.	C-3
Sclater, John G.	GS-11
Scranton, Mary L.	C-18
Seyfried, William E.	C-13,C-15
Shafer, Deborah K.	C-18
Sharp, Arnold G.	OE-7,OE-10
Shibata, Twugio	C-12
*Shih, John S.F.	GS-7
*Shor, Alexander	GG-4,GG-5,GG-13
Shor, George G. Jr.	GG-18
Siegel, Stuart E.	B-11
Skopek, Thomas R.	B-14
Sinton, John	GG-5,GG-6
Smith, Clarence L.	C-18
Smith, Leah J.	MP-3,MP-5,MP-6
Smith, M. Estellie	MP-6

AUTHOR INDEX

	Page No.
Smith, Steven O.	C-5
Smith, Woollcott K.	OE-9
Spencer, Ann	PO-16
Spencer, Derek W.	C-22
Spiller, Judith	MP-5,MP-7
Spindel, Robert C.	OE-5,OE-6,OE-8
Spydell, Randall	C-10
Stalcup, Firuzeh	B-17
Stanier, Roger Y.	B-9,B-11,B-12
*Staresinic, Nick	GS-8
Staudigel, Hubert	C-12;GG-3
Stebbins, Jonathan	C-12
Stegeman, John J.	B-13,B-14
Stenberg, Richard W.	B-4
Stoffers, Peter	C-17;GG-18
Stommel, Henry M.	PO-3
Stroup, Janet	C-10
Sukardi, Sutesna	GG-12
Sullivan, James D.,Jr.	B-11
Summerhayes, Colin P.	GG-18
Takahashi, Taro	GG-19
Tarbell, Susan	PO-16
Taylor, Craig D.	B-11
Teal, John M.	B-20,B-21;C-8
Tenore, Kenneth R.	B-19
Thilly, William G.	B-14
Thompson, Geoffrey	C-1,C-9,C-10,C-11,C-12; GG-3,GG-8,GG-9,GG-10,GG-16
*Tochko, John Steven	GS-9
*Toole, John M.	PO-7
Torgerson, Thomas	C-20
True, Mary B.	C-15,C-16
Tuttle, Jon H.	B-12
Uchupi, Elazar	C-10;GG-5,GG-8,GG-16
*Ulmer, Kevin Michael	GS-10
Vaccaro, Ralph F.	B-22
Valiela, Ivan	B-20,B-21;C-8
Valois, Frederica W.	B-12
Van Andel, Tjeerd H.	OE-6
Veevers, John J.	GG-12,GG-23
Velterop, Jan J.A.	GG-13
de Verdiere, Alain Colin	PO-9
Vermersch, John A.	PO-5,PO-15
Volchok, Herbert L.	C-19
Von Herzen, R.P.	GS-11
Voorhis, Arthur D.	PO-13
Voresmarty, Charles J.	B-20
Wade, Terry	C-7
Walden, Robert G.	OE-7
Warn-Varnas, Alex C.	PO-9
Warren, Bruce A.	PO-3
Wartozok, Douglas	B-7
Watkins, William A.	B-7,B-8
Watson, Stanley W.	B-11,B-12
Waterbury, John B.	B-9, B-11,B-12
Watts, Anthony B.	GG-16
Whelan, Jean K.	C-3,C-4
Whitek Robert S.	GG-14
Wiebe, Peter H.	B-24,B-26
Willebrand, Jurgen	PO-14
Williams, Albert J.,3rd	OE-9
Williams, John R.	C-6
Williams, LeVergne D.	B-4
Winant, Clinton D.	PO-4,PO-6
Wirsen, Carl O.	B-12
Witzell, Warren E.,Jr.	PO-13
Wolke, Richard E.	B-13
Worthington, Valentine	PO-1,PO-4
Wright, Raymond	C-10
Zafiriou, Oliver C.	C-3,C-6,C-15,C-16
Zenk, Walter	PO-7
*Zlotnicki, Victor	GS-11

KEY WORDS

	Page No.
Acoustics	OE-3
Sound channels	OE-3
ALVIN (DSRV), 1978	OE-10
Animals	
deep ocean	B-6
marine	B-23
Antarctic Intermediate Water	PO-13
Antarctic Polar Front Zone	PO-8
Aquaculture	B-3
algae	B-16
cultures	B-3
recycling, waste	B-4
Argo Abyssal Plain	GG-12,GG-23
Atlantic Crust	C-11;GG-10
Bacteria, mud	B-10,B-11,B-12
Basalt, in sea water	C-14
Chemistry	
organic and biological	C-3
radiochemistry	C-19
sea-water	C-15
Clam, Manila	B-3
Continental Slope	B-6
Deep Sea, South of New England	
Deep Ocean drilling	GG-12
Megabenthic fauna	B-5
Denmark Strait	B-8
Fallout	C-19,C-21
Fishes, deep sea	B-8
Galapagos	B-8
Geology	GG-3
Continental Shelf	GG-4
Laurentian Cone Region	GG-5
New England Shelf	GG-7
North Atlantic	GG-4,GG-7
Red Sea	GG-4
Western Pacific	GG-6
Gulf of Maine (western)	PO-5
Gulf of Oman	GG-14
Hydrocarbons	C-3,C-4
aromatic	C-7
Indian Ocean, Equatorial	PO-5
Irminger Sea	B-8
Isopods, Porcellinoid	B-6
Kane Fracture Zone, Central Atlantic	GG-13
Lobsters	B-24
Mediterranean Sea	C-19
Microbiology	B-9
Mid-Atlantic Bight	PO-4
Mid-Cayman Ridge	C-10
Models, Theoretical	PO-9
Moorings, tracking of	OE-5
Ocean Circulation	PO-2
Grand Banks	PO-3
Gulf Stream	PO-3
OCS (Ocean Continental Shelf	MP-5
Ocean dynamics	OE-8
Ocean, West Indian, Amirante Passage	GG-11
Oysters, relic	GG-9
Physiology	B-13
Hydrocarbons	B-13,B-14
Phytoplankton	B-14,B-15,B-16,B-17,B-18,B-19
Plants, Marine and Freshwater	B-4
Radionuclides	C-19
Reflection, ocean bottom	OE-4
Rings and Eddies	PO-3
Rockall Trough	GG-15
Salt Marshes, New England	B-20,B-21
Sargasso Sea	PO-5
Sediments	C-17;GG-18
Amazon River	C-13
Black Sea	C-6
Fraser River	GG-21
SW African Shelf	C-5
Western Atlantic Ocean	C-3
Sensing, remote	OE-4,OE-5
Sharks, Skates and Rays	B-9
Shelves	
Continental Shelf	GG-4
New England Shelf	GG-7
Ocean Continental Shelf	GG-11
Slope, Continental	B-6
Technical Reports	PO-10
Turbulence (geostrophic) and Mixing	PO-6
Water Resources and Renovation	B-22
Waves, Internal	PO-7,PO-8
Whales and Seals	B-7,B-8
Zooplankton	B-22,B-23,B-24,B-25,B-26


END
FILMED
6-84
DTIC