Reference No. 86-2

ABSTRACTS OF PAPERS
SUBMITTED IN 1985 FOR PUBLICATION

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts

Editor: Anne I. Rabushka

APPROVED FOR DISTRIBUTION

Doelw. Jener

When citing this report, it should be referenced
as: Woods Hole Oceanographic Institution
Technical Report WHOI-86-2.

PREFACE

This volume contains all abstracts submitted for publication during calendar year 1985 by the staff and students of the Woods Hole Oceanographic Institution. Because some of the abstracts may not be published in the journal to which they have been submitted initially, we have purposely omitted identifying the journals. The volume is intended to be informative, but not a bibliography.

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

A handwritten signature in dark ink, appearing to read "Derek W. Spencer", is written over a horizontal line.

Derek W. Spencer
Associate Director for Research

TABLE OF CONTENTS

DEPARTMENT OF BIOLOGY

B-1

Animal Physiology and Biochemistry

INDUCTION OF CYTOCHROME P-450-DEPENDENT MONOOXYGENASE SYSTEMS IN EMBRYOS AND ELEUTHEROEMBRYOS OF THE KILLIFISH <u>Fundulus heteroclitus</u>	
Robert L. Binder, John J. Stegeman and John J. Lech	B-3
WARM BRAIN AND EYE TEMPERATURES IN SHARKS	
Barbara A. Block and Francis G. Carey	B-3
TEMPERATURE, HEAT PRODUCTION AND HEAT EXCHANGE IN LAMNID SHARKS	
Francis G. Carey, John G. Casey, Harold L. Pratt, David Urquhart and John E. McCosker	B-3
GLUCOSE TRANSPORT BY THE IN VITRO PERFUSED MIDGUT OF THE BLUE CRAB, <u>Callinectes sapidus</u> I. TRANSMURAL FLUXES	
Ka Hou Chu	B-4
GLUCOSE TRANSPORT BY THE IN VITRO PERFUSED MIDGUT OF THE BLUE CRAB, <u>Callinectes sapidus</u> RATHBUN II. MUCOSAL UPTAKE	
Ka Hou Chu	B-4
GROWTH AND SURVIVAL OF LARVAE OF <u>Mercenaria mercenaria</u> (L.) AND <u>Crassostrea virginica</u> (GMELIN) RELATIVE TO BROODSTOCK CONDITIONING AND LIPID CONTENT OF EGGS	
Scott M. Gallager and Roger Mann	B-5
INDIVIDUAL VARIABILITY IN LIPID CONTENT OF BIVALVE LARVAE QUANTIFIED HISTOCHEMICALLY BY ABSORPTION PHOTOMETRY	
Scott M. Gallager and Roger Mann	B-5
LIPID AS AN INDEX OF GROWTH AND VIABILITY IN THREE SPECIES OF BIVALVE LARVAE	
Scott M. Gallager and Roger Mann	B-6
IN VIVO METABOLISM OF BENZ(a)ANTHRACENE BY THE POLYCHAETE <u>Nereis virens</u>	
Anne E. McElroy	B-6
NUTRITIONAL AND BIOENERGETIC CONSIDERATIONS IN THE EARLY DEVELOPMENT OF THE AMERICAN LOBSTER <u>Homarus americanus</u> MILNE EDWARDS	
Glenn C. Sasaki, Judith M. Capuzzo and Patricia Biesiot	B-7
BENZO[a]PYRENE OXIDATION AND MICROSOMAL ENZYME ACTIVITY IN THE MUSSEL (<u>Mytilus edulis</u>) AND OTHER BIVALVE MOLLUSC SPECIES FROM THE WESTERN N. ATLANTIC	
John Stegeman	B-7
METHODS FOR ANALYSIS OF MONOOXYGENASE SYSTEMS IN MARINE FISH	
John J. Stegeman	B-8
INDIVIDUAL VARIATION IN PATTERNS OF BENZO[a]PYRENE METABOLISM IN THE MARINE FISH SCUP (<u>Stenotomus chrysops</u>)	
John J. Stegeman and Margaret O. James	B-8
MONOOXYGENASE INDUCTION AND CHLOROBIPHENYLS IN THE DEEP SEA FISH <u>Coryphaenoides armatus</u>	
John J. Stegeman, Pamela J. Kloepper-Sams and John W. Farrington	B-8
MICROSOMAL CYTOCHROME P-450 FUNCTION IN FISH EVALUATED WITH POLYCLONAL AND MONOCLONAL ANTIBODIES TO CYTOCHROME P-450E FROM SCUP (<u>Stenotomus chrysops</u>)	
John J. Stegeman, Bruce R. Woodin, Sang S. Park, Pamela J. Kloepper-Sams and Harry V. Gelboin	B-9

Benthos

HYDROTHERMAL VENT ANIMALS: DISTRIBUTION AND BIOLOGY	
J. Frederick Grassle	B-9
THE ECOLOGY OF DEEP SEA HYDROTHERMAL VENT COMMUNITIES	
J. Frederick Grassle	B-9

Biogeography and Systematics

CIRCULATION AROUND ISLANDS AND THE DISPERSAL OF PLANKTONIC LARVAE	
Mary W. Farmer and Carl J. Berg, Jr.	B-10

TOWARD A STUDY OF THE BIOGEOGRAPHY OF PELAGIC CTENOPHORES	
G. Richard Harbison	B-10
THE APLACOPHORAN FAMILY PROCHAETODERMATIDAE IN THE NORTH AMERICAN BASIN, INCLUDING <u>Chevroderma</u> n.g. AND <u>Spathoderma</u> n.g. (MOLLUSCA; CHAETODERMOMORPHA)	
Amelie H. Scheltema	B-10

Ecosystem Studies

Riverine Systems

STRUCTURE AND FUNCTION IN A BENTHIC INVERTEBRATE STREAM COMMUNITY AS INFLUENCED BY BEAVER (<u>Castor canadensis</u>)	
Donald M. McDowell and Robert J. Naiman	B-11
ANADROMOUS BROOK TROUT, <u>Salvelinus fontinalis</u> : OPPORTUNITIES AND CONSTRAINTS FOR POPULATION ENHANCEMENT	
Robert J. Naiman, Stephen D. McCormick, W. Linn Montgomery and Roderick Morin . .	B-11

Salt Marsh Systems

TIDAL FLUSHING OF AN ESTUARINE EMBAYMENT SUBJECT TO RECURRENT DINOFLAGELLATE BLOOMS	
Veronique C. Garcon, Keith D. Stolzenbach and Donald M. Anderson	B-12

Fish

ENCOUNTER WITH A SWORDFISH (<u>Xiphias oladius</u>) AND SHARPTAIL MOLA (<u>Masturus lanceolata</u>) AT A DEPTH GREATER THAN 600 METERS	
John Janssen and G. Richard Harbison	B-12

Geochemistry

SHORT-TERM ENDPRODUCTS OF SULFATE REDUCTION: FORMATION OF ACID VOLATILE SULFIDES, ELEMENTAL SULFUR AND PYRITE	
Gary M. King, Brian L. Howes and John W.H. Dacey	B-12

Marine Mammals

THE USE OF PHOTOGRAPHS TO IDENTIFY INDIVIDUAL NORTH ATLANTIC RIGHT WHALES (<u>Eubalaena glacialis</u>)	
Scott D. Kraus, Karen E. Moore, Carol A. Price, Martie J. Crone, William A. Watkins, Howard E. Winn and John H. Prescott	B-13
THE INTERNATIONAL CODE OF ZOOLOGICAL NOMENCLATURE AND A PARADIGM: THE NAME <u>Physeter catodon</u> LINNAEUS 1758	
William E. Schevill	B-13
AN OPTICAL TELEMETRY DEVICE TO IDENTIFY WHICH DOLPHIN PRODUCES A SOUND	
Peter Tyack	B-13
WHISTLE REPERTOIRES OF TWO BOTTLENOSED DOLPHINS, <u>Tursiops truncatus</u> : MIMICRY OF SIGNATURE WHISTLES?	
Peter Tyack	B-13
CHANGES OBSERVED IN THE REACTION OF WHALES TO HUMAN ACTIVITIES	
William A. Watkins	B-14
THE USE OF RADIO TAGS IN TRACKING LARGE WHALES -- A REVIEW OF PRESENT KNOWLEDGE	
William A. Watkins	B-14
CODAS SHARED BY CARIBBEAN SPERM WHALES	
William A. Watkins, Karen Moore and Peter Tyack	B-15

Marine Pollution

BIOLOGICAL EFFECTS OF PETROLEUM HYDROCARBONS ON MARINE ORGANISMS: INTEGRATION OF EXPERIMENTAL RESULTS AND PREDICTIONS OF IMPACTS	
Judith M. Capuzzo	

ECOLOGICAL AND HUMAN HEALTH CRITERIA FOR CROSS ECOSYSTEM COMPARISON OF
WASTE DISPOSAL IMPACTS

Judith M. Capuzzo, John M. Teal and Robert K. Bastian	B-15
<u>Microbiology</u>	

SYMBIOTIC ASSIMILATION OF CO ₂ IN TWO HYDROTHERMAL VENT ANIMALS, THE MUSSEL <u>Bathymodiolus thermophilus</u> AND THE TUBE WORM <u>Riftia pachyptila</u>	
Shimshon Belkin, Douglas C. Nelson and Holger W. Jannasch	B-16
A NEW SULFUR-REDUCING, EXTREMELY THERMOPHILIC EUBACTERIUM FROM A SUBMARINE THERMAL VENT	
Shimshon Belkin, Carl O. Wirsen and Holger W. Jannasch	B-16
LEBEN IN DER TIEFSEE AUF CHEMOSYNTHETISCHER BASIS	
Holger W. Jannasch	B-16
THE CHEMOSYNTHETIC SUPPORT OF LIFE AND THE MICROBIAL DIVERSITY AT DEEP SEA HYDROTHERMAL VENTS	
Holger W. Jannasch	B-17
A CYANOBACTERIUM CAPABLE OF SWIMMING MOTILITY	
John B. Waterbury, Joanne M. Willey, Diana G. Franks, Frederica W. Valois and Stanley W. Watson	B-17
<u>Nitrospira marina</u> GEN. NOV. SP. NOV.: A CHEMOLITHOTROPHIC NITRITE-OXIDIZING BACTERIUM	
Stanley W. Watson, Eberhard Bock, Frederica W. Valois, John B. Waterbury and Ursula Schlosser	B-17
RATES OF MICROBIAL TRANSFORMATIONS IN DEEP SEA SEDIMENTS: FREE VEHICLE STUDIES	
Carl O. Wirsen and Holger W. Jannasch	B-17
ACTIVITIES OF SULFUR-OXIDIZING BACTERIA AT THE 21°N EAST PACIFIC RISE VENT SITE	
Carl O. Wirsen, Jon H. Tuttle and Holger W. Jannasch	B-18

Plankton Dynamics

THE DINOFLAGELLATES	
Donald M. Anderson	B-18
DINOFLAGELLATE CYST DYNAMICS IN COASTAL AND ESTUARINE WATERS	
Donald M. Anderson and Bruce A. Keafer	B-19
SELECTIVE RETENTION OF TWO DINOFLAGELLATES IN A WELL-MIXED ESTUARINE EMBAYMENT: THE IMPORTANCE OF DIEL VERTICAL MIGRATION AND SURFACE AVOIDANCE	
Donald M. Anderson and Keith D. Stolzenbach	B-19
PRIMARY PRODUCTIVITY AND PELAGIC NITROGEN CYCLING	
Patricia M. Glibert	B-19
ON PHYTOPLANKTON GROWTH RATES AND PARTICULATE C:N:P RATIOS IN CONTINUOUS CULTURES AND PELAGIC SURFACE WATERS	
Joel C. Goldman	B-20
EXPERIMENTAL STUDIES ON AN OMNIVOROUS MICROFLAGELLATE: IMPLICATIONS FOR GRAZING AND NUTRIENT REGENERATION IN THE MARINE MICROBIAL FOOD CHAIN	
Joel C. Goldman and David A. Caron	B-20
NUTRIENT CYCLING IN A MICROFLAGELLATE FOOD CHAIN: I. NITROGEN DYNAMICS	
Joel C. Goldman, David A. Caron, O. Ketil Anderson and Mark R. Dennett	B-21
NUTRIENT CYCLING IN A MICROFLAGELLATE FOOD CHAIN: II. POPULATION DYNAMICS AND CARBON CYCLING	
David A. Caron, Joel C. Goldman, O. Ketil Anderson and Mark R. Dennett	B-21
NUTRIENT CYCLING IN A MICROFLAGELLATE FOOD CHAIN. III. PHOSPHORUS DYNAMICS	
O. Ketil Anderson, Joel C. Goldman, David A. Caron and Mark R. Dennett	B-21
DARK CO ₂ UPTAKE BY THE DIATOM <u>Chaetoceros simplex</u> IN RESPONSE TO NITROGEN PULSING	
Joel C. Goldman and Mark R. Dennett	B-22
THECATE HETEROTROPHIC DINOFLAGELLATES FEEDING BEHAVIOR AND MECHANISMS	
Dean M. Jacobson and Donald M. Anderson	B-22
DIEL PERIODICITY IN THE PHOTOSYNTHETIC CAPACITY OF COASTAL AND OFFSHORE PHYTOPLANKTON ASSEMBLAGES	
Todd M. Kana, Jennifer L. Watts and Patricia M. Glibert	B-23
ENDOGENOUS CONTROL OF SPAWNING IN A MARINE COPEPOD	
Nancy H. Marcus	B-23
POPULATION DYNAMICS OF MARINE COPEPODS: THE IMPORTANCE OF PHOTOPERIODISM	
Nancy H. Marcus	B-23
RESPONSE OF THE BIOLUMINESCENT DINOFLAGELLATE <u>Gonyaulax polyedra</u> TO PARAMETERS OF FLUID MOTION	
G.T. Reynolds, A.J. Walton, D.M. Nosenchuck and D.M. Anderson	B-23

SELECTIVE FEEDING BY Balanion SP. (CILIATA, BALANIONIDAE) ON PHYTOPLANKTON
THAT BEST SUPPORT ITS GROWTH

Diane K. Stoecker, Terry L. Cucci and Clarice M. Yentsch	B-24
EFFECTS OF COPPER AND ZINC ON TWO PLANKTONIC CILIATES	
D. K. Stoecker, W. G. Sunda and L. H. Davis	B-24
DISCRIMINATION BETWEEN PIGMENT TYPES OF MARINE <u>Synechococcus</u> SPP. BY SCANNING SPECTROSCOPY, EPIFLUORESCENCE MICROSCOPY, AND FLOW CYTOMETRY	
A. Michelle Wood, P. K. Horan, K. Muirhead, D. A. Phinney, C. M. Yentsch and J. B. Waterbury	B-24

Population Ecology

THE DEMOGRAPHIC AND EVOLUTIONARY CONSEQUENCES OF PLANKTONIC DEVELOPMENT	
Hal Caswell	B-25
TWO-SEX MODELS FOR STRUCTURED POPULATIONS: DYNAMICS AND STABILITY OF THE SEX RATIO	
Hal Caswell	B-25
ELASTICITY AS A MEASURE OF THE RELATIVE CONTRIBUTION TO POPULATION GROWTH RATE IN MATRIX MODELS	
Hans de Kroon, Anton Plaisier, Jan van Groenenendaal and Hal Caswell	B-25
DEMOGRAPHIC IMPORTANCE OF ECOLOGICAL INTERACTIONS: HOW MUCH DO STATISTICS TELL US?	
James R. Weinberg, Hal Caswell and Robert B. Whitlatch	B-25

Zooplankton

EFFECTS OF STARVATION ON MOULT CYCLE AND HEPATOPANCREAS OF STAGE I LOBSTER (<u>Homarus americanus</u>) LARVAE	
K. Anger, V. Storch, V. Anger and J. M. Capuzzo	B-26
THE STORAGE AND UTILIZATION OF BIOGENIC PARTICULATE MATTER IN DEEP MIXED LAYERS: OBSERVATIONS IN A WARM-CORE RING	
J. K. B. Bishop, M. Conte, P. H. Wiebe and M. R. Roman	B-26
SMALL-SCALE, SHORT-TERM GENETIC HETEROGENEITY IN POPULATIONS OF THE EUPHAUSIIDS, <u>Euphausia krohnii</u> AND <u>Nematoscelis megalops</u> FROM THE WESTERN NORTH ATLANTIC SLOPE WATER	
Ann Bucklin and Peter Wiebe	B-27
A PARASITIC ASSOCIATION BETWEEN A PYCNOGONID AND A SCYPHOMEDUSA IN MIDWATER	
C. Allan Child and G. R. Harbison	B-28
RESPIRATION AND EXCRETION BY OCEANIC SALPS	
Catherine M. Cetta, Laurence P. Madin and Patricia Kremer	B-28
PRESERVATION ARTIFACTS AND THEIR EFFECTS ON THE STUDY OF EUTHECOSOMATOUS PTEROPOD MOLLUSCS	
Ronald Gilmer	B-28
FIELD BEHAVIOR OF PTEROPOD MOLLUSCS: FEEDING METHODS IN THE FAMILIES CAVOLINIIDAE AND PERACLIDIDAE (GASTROPODA, THECOSOMATA)	
Ronald W. Gilmer and G. Richard Harbison	B-28
THE RESPONSE OF THE SALP, <u>Pegea confoederata</u> , TOO HIGH LEVELS OF PARTICULATE MATERIAL: TOO MUCH IS JUST AS BAD AS TOO LITTLE	
G. R. Harbison, V. L. McAlister and R. W. Gilmer	B-29
SWARMING BEHAVIOR OF THE HYPERIID AMPHIPOD <u>Anchylomera blossevilli</u>	
Phillip S. Lobel and John E. Randall	B-29
PRIMARY PRODUCTION AND GRAZING IN THE PLANKTON OF THE PANAMA BIGHT	
John Marra, Peter H. Wiebe and James K. B. Bishop	B-29
NEW DEVELOPMENTS IN THE MOCNESS: AN APPARATUS FOR SAMPLING ZOOPLANKTON AND MICRONEKTON	
Peter H. Wiebe, Alfred W. Morton, Albert M. Bradley, Richard H. Backus, James E. Craddock and Valerie Barber	B-29

TABLE OF CONTENTS

DEPARTMENT OF CHEMISTRY

C-1

Organic and Biological Chemistry

SEASONAL VARIATIONS IN ^{15}N NATURAL ABUNDANCE IN PARTICLES SINKING TO THE DEEP SARGASSO SEA	
Mark A. Altabet and Werner G. Deuser	C-3
PARTITIONING OF PCBs IN MARINE SEDIMENTS	
Bruce J. Brownawell and John W. Farrington	C-3
INPUT OF EXCESS CO_2 TO THE SURFACE OCEAN CALCULATED FROM STABLE CARBON ISOTOPE RATIOS IN A BANDED JAMAICAN SCLEROSPONGE	
Ellen R. M. Druffel and Livia M. Benavides	C-3
FOSSIL FUEL AROMATIC HYDROCARBON BIOGEOCHEMISTRY IN THE MARINE ENVIRONMENT: RESEARCH CHALLENGES	
John W. Farrington	C-4
SOME ASPECTS OF THE BIOGEOCHEMISTRY OF POLYCHLORINATED BIPHENYLS IN THE ACUSHNET RIVER ESTUARY, MASSACHUSETTS, U.S.A.	
J. W. Farrington, A. C. Davis, B. J. Brownawell, B. W. Tripp, C. H. Clifford and J. B. Livramento	C-4
"MUSSEL WATCH" - MEASUREMENTS OF CHEMICAL POLLUTANTS IN BIVALVES AS ONE INDICATOR OF COASTAL ENVIRONMENTAL QUALITY	
J. W. Farrington, A. C. Davis, B. W. Tripp, D. K. Phelps and W. Galloway	C-4
EARLY DIAGENESIS OF AMINO ACIDS AND ORGANIC MATTER IN TWO COASTAL MARINE SEDIMENTS	
Susan M. Henrichs and John W. Farrington	C-4
ACCUMULATION, CYCLING AND LOSS OF AMINO ACIDS IN SALT-MARSH ECOSYSTEMS: BIOLOGICAL AND CHEMICAL MECHANISMS	
Randall E. Hicks, Cindy Lee and Andrew C. Marinucci	C-5
AMINO ACIDS AND AMINES IN MARINE PARTICULATE MATERIAL AND SEDIMENTS	
Cindy Lee	C-5
BIOGEOCHEMISTRY OF PUTRESCINE AND AMINO ACIDS IN OXIC AND ANOXIC WATERS OF A COASTAL SALT POND	
Cindy Lee and Linda A. Hicke	C-6
CARBON-ISOTOPE FRACTIONATION AND CHANGES IN THE FLUX AND COMPOSITION OF PARTICULATE MATTER RESULTING FROM BIOLOGICAL ACTIVITY DURING A SEDIMENT-TRAP EXPERIMENT IN LAKE GREIFEN, SWITZERLAND	
Cindy Lee, Judith A. McKenzie and Michael Sturm	C-6
CHRONOLOGY OF CHOLELITHIASIS	
Henry Y. Mok, Ellen M. Druffel and William M. Rampone	C-6
LIPID COMPOSITION OF THE PELAGIC CRAB <i>Pleuroncodes planipes</i> , ITS FECES, AND SINKING PARTICULATE ORGANIC MATTER IN THE EQUATORIAL NORTH PACIFIC OCEAN	
Stuart G. Wakeham and Elizabeth A. Canuel	C-7
ORGANIC MATTER IN LEG 96 SEDIMENTS - CHARACTERIZATION BY PYROLYSIS	
Jean K. Whelan and Martha Tarafa	C-7
PHENOLIC AND LIGNIN PYROLYSIS PRODUCTS OF PLANTS, SESTON, AND SEDIMENT IN A GEORGIA ESTUARY	
Jean K. Whelan, Martha E. Tarafa and Evelyn B. Sherr	C-8

Radiochemistry

SCLEROSPONGE GROWTH RATE AS DETERMINED BY ^{210}Pb AND $\Delta^{14}\text{C}$ CHRONOLOGIES	
Livia M. Benavides and Ellen R. M. Druffel	C-8
$^{239,240}\text{Pu}$ AND EXCESS ^{210}Pb INVENTORIES ALONG THE SHELF AND SLOPE OF THE NORTHEAST U.S.A.	
Ken O. Buesseler, Hugh D. Livingston and Edward R. Sholkovitz	C-8
DETERMINATION OF THORIUM CONCENTRATION IN SEAWATER BY NEUTRON ACTIVATION ANALYSIS	
C.-A. Huh and M. P. Bacon	C-8
THORIUM-232 IN THE EASTERN CARIBBEAN SEA	
C.-A. Huh and M. P. Bacon	C-9
ANTHROPOGENIC RADIOTRACER EVOLUTION IN THE CENTRAL GREENLAND SEA	
Hugh D. Livingston	C-9

Seawater and Geochemistry

THE REACTION OF SUPEROXIDE WITH NITRIC OXIDE TO FORM PEROXONITRITE IN ALKALINE AQUEOUS SOLUTION	
Neil V. Blough and Oliver C. Zafiriou	C-10
TEMPORAL VARIABILITY OF LEAD IN THE WESTERN NORTH ATLANTIC OCEAN	
E. A. Boyle, S. D. Chapnick, G. T. Shen and M. P. Bacon	C-10
RAPID MICROBIAL METABOLISM OF NON-PROTEIN AMINO ACIDS IN THE SEA	
J. J. Cole and C. Lee	C-10
SEASONAL AND INTERANNUAL VARIATIONS IN DEEP-WATER PARTICLE FLUXES IN THE SARGASSO SEA AND THEIR RELATION TO SURFACE HYDROGRAPHY	
W. G. Deuser	C-10
RADIOCARBON IN PARTICULATE MATTER FROM THE EASTERN SUB-ARCTIC PACIFIC OCEAN: RESULTS FROM A SEDIMENT TRAP EXPERIMENT	
E. R. M. Druffel, S. Honjo, S. M. Griffin and C. S. Wong	C-11
ORGANIC CHEMICAL POLLUTANTS IN THE OCEANS AND GROUNDWATER: A REVIEW OF FUNDAMENTAL CHEMICAL PROPERTIES AND BIOGEOCHEMISTRY	
John Farrington and John Westall	C-11
THE AIR-SEA EXCHANGE OF PARTICULATE ORGANIC MATTER: THE SOURCES AND LONG-RANGE TRANSPORT OF LIPIDS IN AEROSOLS	
Robert B. Gagosian	C-11
THE CHEMISTRY AND MINERALOGY OF FERROMANGANESE ENCRUSTATIONS ON ROCKS FROM THE SIERRA LEONE RISE, THE EQUATORIAL MID-ATLANTIC RIDGE AND THE NEW ENGLAND SEAMOUNT CHAIN	
D. A. Goddard, G. Thompson, E. J. W. Jones and H. Okada	C-12
FIELD AND LABORATORY STUDIES ON THE ONTOGENY AND ECOLOGY OF SOME GLOBOROTALIID SPECIES FROM THE SARGASSO SEA OFF BERMUDA	
C. Hemleben, M. Spindler, I. Breitingner and W. G. Deuser	C-12
PRIMARY AND SECONDARY MIGRATION OF OIL	
John M. Hunt	C-13
³ H AND ³ He IN THE BETA TRIANGLE: OBSERVATIONS OF GYRE VENTILATION AND OXYGEN UTILIZATION RATES	
William J. Jenkins	C-13
THE FLUX OF SYNTHETIC ORGANIC CHEMICALS TO THE DEEP SARGASSO SEA	
Anthony H. Knap, Kandace Binkley and Werner G. Deuser	C-13
COSMOGENIC HELIUM IN A TERRESTRIAL IGNEOUS ROCK	
Mark D. Kurz	C-14
CHRONOLOGY OF SELECTED HYDROTHERMAL Mn OXIDE DEPOSITS FROM THE TRANSATLANTIC GEOTRAVERSE "TAG" AREA, MID-ATLANTIC RIDGE 26°N	
C. Lalou, G. Thompson and P.A. Rona	C-14
OXYGEN ISOTOPE RATIOS OF THE PORE FLUIDS OF OCEAN SEDIMENTS NEAR THE COSTA RICA RIFT REVEAL A TIME HISTORY OF BASALT ALTERATION AND SEDIMENT DIAGENESIS	
J. R. Lawrence, M. J. Mottl, M. Taviani, Y.-H. Li and J. Rosenbaum	C-14
THE NITROGEN ISOTOPE GEOCHEMISTRY OF MARINE PARTICLES IN THE GULF OF MAINE	
S. M. Libes and W. G. Deuser	C-14
THE NITROGEN ISOTOPE GEOCHEMISTRY OF MARINE PARTICLES IN THE PERU UPWELLING AREA	
S. M. Libes and W. G. Deuser	C-15
THE GEOLOGICAL FORM AND SETTING OF A HYDROTHERMAL VENT FIELD AT 10°56'N, EAST PACIFIC RISE: A DETAILED STUDY USING ANGUS AND ALVIN	
T. F. McConachy, R. D. Ballard, M. J. Mottl and R. P. Von Herzen	C-15
ACOUSTIC IMAGING OF HIGH-TEMPERATURE HYDROTHERMAL PLUMES AT SEAFLOOR SPREADING CENTERS	
D. R. Palmer, P. A. Rona and M. J. Mottl	C-15
HYDROCARBON GEOCHEMISTRY AND BIOLOGICAL MARKERS IN ORCA AND PYGMY BASIN SEDIMENTS (SITES 618 AND 619)	
A. G. Requejo, Jean K. Whelan and Paul D. Boehm	C-16
TEMPORAL CHANGES IN THE HYDROGRAPHY AND CHEMISTRY OF THE CARIACO TRENCH	
Mary I. Scranton, Frederick L. Sayles, Michael P. Bacon and Peter G. Brewer	C-16
SEDIMENT SLUMPS IN THE MIDDLE AND EARLY EOCENE OF DSDP HOLES 605 AND 613 - CHEMICAL DETECTION VIA PYROLYSIS TECHNIQUES	
Martha E. Tarafa, Jean K. Whelan and Gregory S. Mountain	C-16
AXIAL PROCESSES ALONG A SEGMENT OF THE EAST PACIFIC RISE, 10°-12°N	
G. Thompson, W. B. Bryan, R. Ballard, K. Hamuro and W. G. Melson	C-17
REACTION OF Br ₂ PRODUCED BY FLASH PHOTOLYSIS OF SEAWATER WITH COMPONENTS OF THE DISSOLVED CARBONATE SYSTEM	
Mary B. True and Oliver C. Zafiriou	C-17
GEOCHEMISTRY OF VOLATILE ORGANIC COMPOUNDS IN SEAWATER	
Stuart G. Wakeham, Elizabeth A. Canuel and Peter H. Doering	C-17

THE BEHAVIOR OF ALIPHATIC HYDROCARBONS IN COASTAL SEAWATER: MESOCOSM EXPERIMENTS WITH ^{14}C -OCTADECANE AND ^{14}C -DECANE	
Stuart G. Wakeham, Elizabeth A. Canuel and Peter H. Doering	C-18
C1-C8 HYDROCARBONS IN SEDIMENTS FROM THE LOWER CONTINENTAL RISE, DSDP SITE 603	
Jean K. Whelan and Christine Burton	C-18
EVIDENCE FOR SULFATE REDUCING AND METHANE PRODUCING MICRO-ORGANISMS IN SEDIMENTS FROM SITES 618, 619 AND 622	
Jean K. Whelan, Ronald Oremland, Martha Tarafa, Richard Smith, Robert Howarth and Cindy Lee	C-18
WAVELENGTH-DEPENDENT QUANTUM YIELD OF OH RADICAL FORMATION FROM PHOTOLYSIS OF NITRITE ION IN WATER	
Oliver C. Zafiriou and Roland Bonneau	C-18
INTERFERENCES IN ENVIRONMENTAL ANALYSIS OF NO BY (NO + O ₃) DETECTORS: A RAPID SCREENING TECHNIQUE	
Oliver C. Zafiriou and Mary B. True	C-19
CONSEQUENCES OF OH RADICAL REACTION IN SEAWATER: FORMATION AND DECAY OF Br ₂ ⁻ ION-RADICAL	
O.C. Zafiriou, M.B. True and E. Hayon	C-19

TABLE OF CONTENTS

DEPARTMENT OF GEOLOGY AND GEOPHYSICS

GG-1

Geology

AUSTRALIA---A STABLE PLATFORM FOR TIDE-GAUGE MEASUREMENTS OF CHANGING SEA LEVELS?	
D. G. Aubrey and K. O. Emery	GG-3
PALEOGENE CALCAREOUS NANNOPLANKTON BIOSTRATIGRAPHY OF NORTHWESTERN EUROPE	
Marie-Pierre Aubry	GG-3
A REPORT PREPARED FOR WORKSHOP A4: NEOGENE CHRONOLOGY AND CHRONOSTRATIGRAPHY - NEW DATA BASED ON RECENT ISOTOPIC, PALEOMAGNETIC, AND BIOSTRATIGRAPHIC STUDIES	
W. A. Berggren	GG-3
RESOURCE POTENTIAL OF THE WESTERN NORTH ATLANTIC BASIN	
W. P. Dillon, F. T. Manheim, L. F. Jansa, G. Palmason, B. E. Tucholke and R. S. Landrum	GG-4
GLACIAL REBOUND AND RELATIVE SEA LEVELS IN EUROPE FROM TIDE-GAUGE RECORDS	
K. O. Emery and D. G. Aubrey	GG-4
RELATIVE SEA-LEVEL CHANGE FROM TIDE-GAUGE RECORDS OF WESTERN NORTH AMERICA	
K. O. Emery and D. G. Aubrey	GG-4
RELATIVE SEA-LEVEL CHANGES FROM TIDE-GAUGE RECORDS OF EASTERN ASIA MAINLAND	
K. O. Emery and D. G. Aubrey	GG-5
THE GEOLOGY OF THE OCEANOGRAPHER TRANSFORM: THE TRANSFORM DOMAIN	
P. J. Fox, R. H. Moody, J. A. Karson, E. Bonatti, K. Crane, W. S. F. Kidd, D. G. Gallo, J. B. Stroup, D. J. Fornari, D. Elthon, P. Hamlyn, J. F. Casey, D. Needham and R. Sartori	GG-5
SEDIMENTATION, RESUSPENSION AND CHEMISTRY OF PARTICLES IN THE NORTHWEST ATLANTIC	
Wilford D. Gardner, John B. Southard and Charles D. Hollister	GG-6
TECTONICS OF SHORT-OFFSET, SLOW-SLIPPING TRANSFORM ZONES IN THE FAMOUS AREA, MID-ATLANTIC RIDGE	
Margaret R. Goud and Jeffrey A. Karson	GG-6
STABLE ISOTOPE STRATIGRAPHY AT THE CRETACEOUS/TERTIARY BOUNDARY IN DENMARK	
Michael A. Kaminski and Bjorn A. Malmgren	GG-7
GEOLOGICAL AND GEOPHYSICAL INVESTIGATION OF THE MID-CAYMAN SPREADING CENTER: SEISMIC VELOCITY MEASUREMENTS AND IMPLICATIONS FOR THE CONSTITUTION OF LAYER 3	
J. A. Karson and P. J. Fox	GG-7
NORTH ATLANTIC LATE MIOCENE STABLE ISOTOPE STRATIGRAPHY, BIOSTRATIGRAPHY AND MAGNETOSTRATIGRAPHY	
L. D. Keigwin, M.-P. Aubry and D. V. Kent	GG-7
EARLY MOTION OF THE PLATES AROUND THE NORTHERN ATLANTIC DURING THE LATE JURASSIC- EARLY CRETACEOUS RIFTING	
Jacques A. Malod, Kim D. Klitgord and Hans Schouten	GG-8
DEEP CURRENT-CONTROLLED SEDIMENTATION IN THE WESTERN NORTH ATLANTIC	
I. N. McCave and Brian E. Tucholke	GG-8
GEOLOGY OF THE GULF OF THE PERSIAN GULF: GULF OF OMAN REGION: A SYNTHESIS	
David A. Ross, Elazar Uchupi and Robert S. White	GG-9
SEISMIC STRATIGRAPHIC CORRELATION ACROSS THE NEW ENGLAND SEAMOUNTS, WESTERN NORTH ATLANTIC	
Stephen A. Swift, Cynthia J. Ebinger and Brian E. Tucholke	GG-9
STRUCTURE OF BASEMENT AND DISTRIBUTION OF SEDIMENTS IN THE WESTERN NORTH ATLANTIC	
Brian E. Tucholke	GG-9
BASEMENT STRUCTURE AND SEDIMENT DISTRIBUTION IN THE NORTHWEST ATLANTIC OCEAN	
Brian E. Tucholke and Virginia A. Fry	GG-10
PALEOGEOGRAPHIC AND PALEOBATHYMETRIC EVOLUTION OF THE NORTH ATLANTIC OCEAN	
Brian E. Tucholke and Floyd W. McCoy	GG-10
THE CHARACTERISTICS OF THE CHINA COASTLINE	
Ying Wang and David G. Aubrey	GG-11

Geophysics

GRAVITY AND GEOID ANOMALIES OF THE CARIBBEAN REGION: A PROGRESS REPORT	
Carl Bowin	GG-11

GEOPHYSICAL DATA BASE AND PROCESSING SYSTEM

Carl Bowin and Julie Allen	GG-12
MASS ANOMALIES FROM COMBINED INVERSIONS OF GRAVITY, GEOID, AND GRAVITY	
GRADIENT ANOMALIES	
Carl Bowin, Edward Scheer and Woolfcott Smith	GG-12
A COMPARISON OF HIGH-RESOLUTION SEISMIC METHODS FOR DETERMINING SEABED VELOCITIES	
IN SHALLOW WATER	
T. M. Brocher and J. I. Ewing	GG-12
INNER CORE EXPERIMENTS: TELESEISMIC EXPLORATION OF THE ANTIPODE	
Rhett Butler, Thomas M. Brocher, Jose A. Rial and Charles F. Richter	GG-13
CONTROLLED SOURCE ELECTROMAGNETIC SOUNDING OF THE OCEANIC LITHOSPHERE	
C. S. Cox, S. C. Constable, A. D. Chave and S. C. Webb	GG-13
THERMAL AND MECHANICAL CONSTRAINTS ON THE LITHOSPHERE BENEATH THE MARQUESAS SWELL	
Karen M. Fischer, Marcia K. McNutt and Loren Shure	GG-13
THE SPREADING RATE DEPENDENCE OF OCEANIC SEISMIC LAYER 2	
L. Kong, T. M. Brocher and R. A. Stephen	GG-14
THERMAL CONDUCTIVITY VARIATION IN A DEEP-SEA SEDIMENT CORE AND ITS RELATION TO	
H ₂ O, Ca AND Si CONTENT	
Jun-Ichi Matsuda and R.P. Von Herzen	GG-14
ESTIMATING THE COMPENSATION DEPTH OF THE HAWAIIAN SWELL WITH LINEAR FILTERS	
Marcia McNutt and Loren Shure	GG-14
THE CRUSTAL STRUCTURE OF THE MID-ATLANTIC RIDGE AT 23°N FROM SEISMIC REFRACTION STUDIES	
G. M. Purdy and Robert S. Detrick	GG-14
THE ACCURACY OF MODELS DERIVED BY WKBJ WAVEFORM INVERSION	
Peter R. Shaw	GG-15
SEISMIC ANISOTROPY IN THE UPPER OCEANIC CRUST	
R. A. Stephen	GG-15
A MULTICHANNEL SEISMIC STUDY OF LITHOSPHERIC FLEXURE ACROSS THE HAWAIIAN-EMPEROR	
SEAMOUNT CHAIN	
A. B. Watts, U. S. ten Brink, P. Buhl and T. M. Brocher	GG-16
COHERENT PRESSURE FLUCTUATIONS OBSERVED AT TWO SITES ON THE DEEP SEA FLOOR	
Spahr C. Webb	GG-16
MICROSEISM PROPAGATION BETWEEN TWO SITES ON THE DEEP SEA FLOOR	
Spahr C. Webb and Steven C. Constable	GG-16

Paleoceanography

COMPARISON OF ATLANTIC AND PACIFIC PALEOCHEMICAL RECORDS FOR THE LAST 215,000 YRS:	
CHANGES IN DEEP OCEAN CIRCULATION AND CHEMICAL INVENTORIES	
E. A. Boyle and L. D. Keigwin	GG-17
MIDDLE PLIOCENE CHANGE IN PLANKTONIC FORAMINIFERAL FAUNA AT SITE 606	
Lisa M. Ehrmann and Lloyd D. Keigwin	GG-17
PLIOCENE STABLE ISOTOPE RECORD OF DSDP SITE 606: SEQUENTIAL EVENTS OF ¹⁸ O	
ENRICHMENT BEGINNING AT 3.1 MA	
L. D. Keigwin, Jr.	GG-17
STABLE ISOTOPES IN LATE MIDDLE EOCENE TO OLIGOCENE FORAMINIFERA	
Lloyd D. Keigwin and Bruce H. Corliss	GG-18
LATE QUATERNARY STABLE ISOTOPE PALEOCEANOGRAPHY OFF SOUTHERN CALIFORNIA	
Gao Liang, K. O. Emery and L. D. Keigwin	GG-18

Paleontology

HANDBOOK OF CENOZOIC CALCAREOUS NANNOFOSSILS: VOLUME 1: DISCOASTERS,	
VOLUME 2: GATHOLITHAE, VOLUME 3: HELIOLITHAE	
Marie-Pierre Aubry	GG-19
GEOCHRONOLOGY OF THE EOCENE/OLIGOCENE BOUNDARY	
W. A. Berggren	GG-19
NON-SYNCHRONEITY IN LATE CENOZOIC RADIOLARIAN EVENTS OF THE EQUATORIAL INDO-PACIFIC	
David A. Johnson and Catherine A. Nigrini	GG-19
SYNCHRONOUS AND TIME-TRANSGRESSIVE NEOGENE RADIOLARIAN DATUM LEVELS IN THE EQUATORIAL	
INDIAN AND PACIFIC OCEANS	
David A. Johnson and Catherine A. Nigrini	GG-19
NEOGENE ANTARCTIC RADIOLARIA	
David Lazarus	GG-20

THREE-DIMENSIONAL MEASUREMENT OF MICROFOSSIL MORPHOLOGY	
David B. Lazarus	GG-20
TEMPO AND MODE OF MORPHOLOGIC EVOLUTION NEAR THE ORIGIN OF THE RADIOLARIAN LINEAGE	
<u>P. prismatium</u>	
David Lazarus	GG-21

Petrology

LINKED EVOLUTIONARY DATA ARRAYS: A LOGICAL STRUCTURE FOR PETROLOGIC MODELLING OF MULTI-SOURCE, MULTI-PROCESS MAGMATIC SYSTEMS	
W. B. Bryan	GG-21
VOLCANIC PROCESSES AND THE EVOLUTION OF LAYER 2 IN THE WESTERN NORTH ATLANTIC	
W. B. Bryan and F. A. Frey	GG-21
PETROLOGY AND GEOCHEMISTRY OF BASALTS FROM THE AMERICAN-ANTARCTIC RIDGE, SOUTHERN OCEAN: IMPLICATIONS FOR THE WESTWARD INFLUENCE OF THE BOUVET MANTLE PLUME	
Anton P. le Roex, Henry J. B. Dick, Arch M. Reid, Fred A. Frey, Anthony J. Erlank and Stan R. Hart	GG-22

Sedimentology

HYDRODYNAMIC CONTROLS ON SEDIMENT TRANSPORT IN WELL-MIXED BAYS AND ESTUARIES	
D. G. Aubrey	GG-23
CALCIUM CARBONATE SUSPENDED IN ARABIAN GULF AND RED SEA WATERS: BIOGENIC AND DETRITAL, NOT "CHEMOGENIC"	
J. P. Ellis and J. D. Milliman	GG-23
EVALUATION OF A LASER DIFFRACTION SIZE ANALYZER FOR USE WITH NATURAL SEDIMENTS	
I. N. McCave, R. J. Bryant, H. Cook and C. A. Coughanowr	GG-24
SILICOFLAGELLATES AND <u>Actiniscus</u> : VERTICAL FLUXES AT PACIFIC AND ATLANTIC SEDIMENT TRAP STATIONS	
Kozo Takahashi	GG-24
SEASONAL FLUXES OF PELAGIC DIATOMS IN THE SUBARCTIC PACIFIC, 1982-1983	
Kozo Takahashi	GG-24
ECOPHENOTIPIC SIZE CHANGES OF <u>Coscinodiscus marginatus</u> (DIATOM)	
Kozo Takahashi	GG-25

Instrumentation

MEASUREMENT ERRORS FOR ELECTROMAGNETIC CURRENT METERS	
David G. Aubrey	GG-25

Technical Reports

TWO YEAR TIME-SERIES FLUXES OF SILICOFLAGELLATES AND <u>Actiniscus</u> : SIZE FRACTIONED RESULTS FROM SUBARCTIC PACIFIC STATION PAPA, 1982-1984	
Kozo Takahashi	GG-25
PELAGIC DIATOM FLUXES I: SIZE FRACTIONED TIME-SERIES RESULTS FROM SUBARCTIC PACIFIC STATION PAPA DURING 1982-1983	
Kozo Takahashi, Danielle N. Povio, John D. Billings and Steven J. Manganini	GG-26

TABLE OF CONTENTS

DEPARTMENT OF OCEAN ENGINEERING

OE-1

Acoustic Signal Processing

BANDWIDTH EXTRAPOLATION THROUGH ITERATIVE DECONVOLUTION

Jules S. Jaffe OE-3

SUPER RESOLUTION OF ACOUSTIC TOMOGRAPHY MULTIPATH DATA

Jules S. Jaffe OE-3

SYNTHETIC APERTURE IMAGE HOLOGRAPHY

Tomamasa Sato and Jules S. Jaffe OE-4

LOWER BOUNDS IN PARAMETER ESTIMATION

A. J. Weiss and E. Weinstein OE-4

Fluid Dynamics

LARVAL SETTLEMENT OF SOFT-SEDIMENT INVERTEBRATES: SOME PREDICTIONS BASED ON AN ANALYSIS OF NEAR-BOTTOM VELOCITY PROFILES

Cheryl Ann Butman OE-4

SEDIMENT TRAP BIASES IN TURBULENT FLOWS: RESULTS FROM A LABORATORY FLUME STUDY

Cheryl Ann Butman OE-5

PREDICTIONS OF SEDIMENT TRAP BIASES IN TURBULENT FLOWS: A THEORETICAL ANALYSIS BASED ON OBSERVATIONS FROM THE LITERATURE

Cheryl Ann Butman, William D. Grant and Keith D. Stolzenbach OE-5

THE CONTINENTAL SHELF BOTTOM BOUNDARY LAYER

W. D. Grant and O. S. Madsen OE-6

MODELING TIME DEPENDENCE IN A TIDAL BOUNDARY LAYER

Thomas F. Gross OE-7

SPECTRAL SCALING IN A TIDAL BOUNDARY LAYER

Thomas F. Gross and Arthur R. M. Nowell OE-7

HYDRODYNAMIC FORCE ON CIRCULAR CYLINDERS

Ole Secher Madsen OE-7

Image Processing

A COMPUTER MODEL FOR PREDICTION OF UNDERWATER IMAGES

Jules S. Jaffe, Stewart E. Harris and Robert Squires OE-7

Instrumentation

THE ALVIN UPSTREAM COLLECTOR

John J. Akens OE-8

IMPROVEMENT OF INTERMEDIATE OCEANOGRAPHIC WINCHES

H. O. Berteaux, R. G. Walden, L. W. Bonde and J. D. Bird OE-8

SINGLE SHIP LARGE OFFSET SEISMIC PROFILING USING A SURFACE TOWED RADIO TELEMETRY ARRAY (STRATA)*

H. O. Berteaux, G. M. Purdy and W. Witzell OE-8

A FREE OCEAN VEHICLE TO MEASURE OPTICAL MICROSTRUCTURE

Christopher H. Converse, Albert J. Williams 3rd, Paul D. Fucile and Raymond W. Schmitt OE-9

THE VAX GENERATION: MANAGEMENT DECISIONS

Robert C. Groman OE-9

CHEMISTRY OF SUBMARINE HYDROTHERMAL SOLUTIONS AT 21°N, EAST PACIFIC RISE

K. L. Von Damm, J. M. Edmond, B. Grant, C. I. Measures, B. Walden and R. F. Weiss OE-9

ACOUSTIC ARRAY SENSOR TRACKING SYSTEM

Keith von der Heydt, Gregory L. Duckworth and Arthur B. Baggeroer OE-10

NEW DEVELOPMENTS IN THE MOCNESS, AN APPARATUS FOR SAMPLING ZOOPLANKTON AND MICRONEKTON

P. H. Wiebe, A. W. Morton, A. M. Bradley, R. H. Backus, J. E. Craddock, V. Barber, T. J. Cowles and G. R. Flierl OE-10

Ocean Acoustics

TOMOGRAPHIC MAPS OF THE OCEAN MESOSCALE. PART 1: PURE ACOUSTICS

B. Cornuelle, C. Wunsch, D. Behringer, T. Birdsall, M. Brown, R. Heinmiller, R. Knox, K. Metzger, W. Munk, J. Spiesberger, R. Spindel, D. Webb and P. Worcester	OE-10
ACOUSTIC MODE PROPAGATION IN A RANGE DEPENDENT OCEAN Yves Desaubies, Ching-Sang Chiu and James Miller	OE-11
GEOACOUSTIC MODELS FOR THE ICELANDIC BASIN George V. Frisk, Earl E. Hays and James A. Douth	OE-11
ANTISUBMARINE WARFARE Robert C. Spindel	OE-11
ARCTIC ACOUSTIC TOMOGRAPHY MIZEX 84 Robert C. Spindel	OE-12
OCEAN ACOUSTIC TOMOGRAPHY: A REVIEW Robert C. Spindel	OE-12
RECIPROCAL ACOUSTIC TRANSMISSIONS: INSTRUMENTATION FOR MESOSCALE MONITORING OF OCEAN CURRENTS P. F. Worcester, R. C. Spindel and B. M. Howe	OE-13

Underwater Robotics

DEMONSTRATION OF CLOSED-LOOP TRAJECTORY CONTROL OF AN UNDERWATER VEHICLE

Dana R. Yoerger and James B. Newman	OE-13
ROBUST TRAJECTORY CONTROL OF UNDERWATER VEHICLES Dana R. Yoerger and Jean-Jacques E. Slotine	OE-13

Underwater Surveys

HOW WE FOUND TITANIC

Robert D. Ballard	OE-13
THE GEOLOGICAL FORM AND SETTING OF A HYDROTHERMAL VENTFIELD AT 10 56'N, EAST PACIFIC RISE: A DETAILED STUDY USING ANGUS AND ALVIN T. F. McConachy, R. D. Ballard, M. J. Mottl and R. P. Von Herzen	OE-14

TABLE OF CONTENTS

DEPARTMENT OF PHYSICAL OCEANOGRAPHY

PO-1

Coastal Circulation and Dynamics

SCATTERING OF LONG COASTAL-TRAPPED WAVES DUE TO BOTTOM IRREGULARITIES	
Kenneth H. Brink	PO-3
TOPOGRAPHIC DRAG DUE TO BAROTROPIC FLOW OVER THE CONTINENTAL SHELF AND SLOPE	
Kenneth H. Brink	PO-3
CIRCULATION IN THE POINT CONCEPTION-SANTA BARBARA CHANNEL REGION	
Kenneth H. Brink and Robin D. Muench	PO-3
A SIMPLE MODEL OF THE FORMATION AND MAINTENANCE OF THE SHELF/SLOPE FRONT IN THE MIDDLE ATLANTIC BIGHT	
David C. Chapman	PO-3
ON THE CONTINUITY OF MEAN FLOW BETWEEN THE SCOTIAN SHELF AND THE MIDDLE ATLANTIC BIGHT	
David C. Chapman, John A. Barth, Robert C. Beardsley and Richard G. Fairbanks . .	PO-4
ASSESSING HAZARDS DUE TO CONTAMINANT DISCHARGE IN COASTAL WATERS	
James H. Churchill	PO-4
MEAN CURRENTS DRIVEN BY TOPOGRAPHIC DRAG OVER THE CONTINENTAL SHELF AND SLOPE	
Dale B. Haidvogel and Kenneth H. Brink	PO-4
WESTWARD INTENSIFICATION OF THE MEAN CIRCULATION ON THE BERING SEA SHELF	
Thomas H. Kinder, David C. Chapman and John A. Whitehead, Jr.	PO-4
INTERANNUAL VARIABILITY OF COASTAL AND SLOPE WATER MASSES ALONG THE WESTERN NORTH ATLANTIC	
Vincent D. Lyne and Charles N. Flagg	PO-5

Instrumentation and Experimental Methodology

A COMPARISON OF THE VACM AND NEW EG&G VMCM ON A SURFACE MOORING IN CODE-1	
Robert C. Beardsley	PO-5
AN EMPIRICAL EQUATION OF STATE FOR PURE WATER IN THE OCEANOGRAPHIC REGION OF TEMPERATURE AND PRESSURE DETERMINED FROM DIRECT MEASUREMENTS	
Alvin L. Bradshaw and Karl E. Schleicher	PO-6
A NOTE ON THE CORRECTION OF TEMPERATURE AND VELOCITY TIME SERIES FOR MOORING MOTION	
Nelson G. Hogg	PO-6

Laboratory Models

BUOYANCY DRIVEN INSTABILITIES OF LOW VISCOSITY ZONES AS MODELS OF MAGMA-RICH ZONES	
John A. Whitehead, Jr.	PO-7
FLOW OF A HOMOGENEOUS ROTATING FLUID THROUGH STRAITS	
John A. Whitehead, Jr.	PO-7

Large Scale Oceanic Heat Transport and Water Properties

WHAT CONTROLS THE RATE OF EQUATORIAL WARM WATER MASS FORMATION?	
Gabriel T. Csanady	PO-7
HYDROGRAPHIC SECTIONS IN THE KUROSHIO EXTENSION AT 165°E AND 175°W	
Terrence M. Joyce	PO-8
ON THE GEOTHERMAL HEATING OF THE ABYSSAL SUBARCTIC PACIFIC OCEAN	
Terrence M. Joyce, Bruce A. Warren and Lynne D. Talley	PO-8

Ocean Circulation

LATE QUATERNARY DEEP-OCEAN CIRCULATION	
Bruce H. Corliss, Douglas G. Martinson and Thomas Keffer	PO-8
HORIZONTAL AND VERTICAL STRUCTURE OF THE GULF STREAM VELOCITY FIELD AT 68°W	
Melinda M. Hall	PO-9

ZONAL PENETRATION SCALE OF MODEL MIDLATITUDE JETS	
William R. Holland and William J. Schmitz, Jr.	PO-9
SYNOPTIC GULF STREAM VELOCITY PROFILES THROUGH SIMULTANEOUS INVERSION OF HYDROGRAPHIC AND ACOUSTIC DOPPLER DATA	
Terrence M. Joyce, Carl I. Wunsch and Stephen D. Pierce	PO-9
A QUASI-SYNOPTIC SURVEY OF THE CIRCULATION AND WATER MASS DISTRIBUTION WITHIN THE CANARY BASIN	
Rolf H. Käse, James F. Price, Philip L. Richardson and Walter Zenk	PO-10
EASTERN PACIFIC OCEAN CIRCULATION NEAR THE ONSET OF THE 1982/83 EL NINO	
Linda J. Mangum, Stanley P. Hayes and John M. Toole	PO-10
MAPPING CLIMATOLOGICAL SEASONAL VARIATIONS OF SURFACE CURRENTS IN THE TROPICAL ATLANTIC USING SHIP DRIFTS	
Philip L. Richardson and David Walsh	PO-10

Rings, Eddies

A CYCLONIC EDDY AND SHELF/SLOPE WATER EXCHANGE ASSOCIATED WITH A GULF STREAM WARM-CORE RING	
James H. Churchill, Peter C. Cornillon and George W. Milkowski	PO-11
THE POLYMODE ATLAS	
Vladimir M. Kamenkovich, Andrei S. Monin and Arthur D. Voorhis, eds.	PO-11
INTERCOMPARISONS OF THE ZONAL, VERTICAL AND TEMPORAL SCALES OF OBSERVED AND MODELLED EDDY KINETIC ENERGY DISTRIBUTIONS NEAR NORTHERN HEMISPHERE MID-LATITUDE JETS	
William J. Schmitz, Jr. and William R. Holland	PO-12

Theoretical Models

ON THE ROLE OF TOPOGRAPHY IN THE OCEAN CIRCULATION	
Paola Cessi and Joseph Pedlosky	PO-12
MECHANISMS OF OCEANIC SUBDUCTION	
Joyce M. Federiuk and James F. Price	PO-12
A DIAGNOSTIC INVESTIGATION OF KINETIC ENERGY BUDGETS IN A NUMERICAL MODEL	
Melinda M. Hall	PO-13
A NUMERICAL STUDY OF BAROCLINIC INSTABILITY AT LARGE SUPERCRITICALITY	
J. Patrice Klein and Joseph Pedlosky	PO-13
EXPERIMENTS WITH CROSS-GYRE FLOW PATTERNS ON A BETA-PLANE	
James R. Luyten and Henry M. Stommel	PO-14
GYRES DRIVEN BY COMBINED WIND AND BUOYANCY FLUX	
James R. Luyten and Henry M. Stommel	PO-14
THE BUOYANCY AND WIND-DRIVEN VENTILATED THERMOCLINE	
Joseph Pedlosky	PO-14

Turbulence and Mixing, Fine- and Micro-scale Processes

THE RELATIONSHIP BETWEEN VERTICAL, DIAPYCNAL, AND ISOPYCNAL VELOCITY AND MIXING IN THE OCEAN GENERAL CIRCULATION	
Sara L. Bennett	PO-15
MASS TRANSFER TO AND FROM SMALL PARTICLES IN THE SEA	
Gabriel T. Csanady	PO-15

Upper Ocean, Surface Layer Processes and Meteorology

WHITECAPS AND THE PASSIVE REMOTE SENSING OF THE OCEAN SURFACE	
Edward C. Monahan and Iognaid G. O'Muircheartaigh	PO-15
THE FRONTAL AIR-SEA INTERACTION EXPERIMENT (FASINEX): A STUDY IN THE BEHAVIOR OF THE COUPLED ATMOSPHERIC AND OCEANIC BOUNDARY LAYERS IN THE VICINITY OF AN OCEANIC FRONT, PART I: BACKGROUND AND SCIENTIFIC OBJECTIVES	
Steven A. Stage and Robert A. Weller	PO-16
THE FRONTAL AIR-SEA INTERACTION EXPERIMENT (FASINEX): A STUDY IN THE BEHAVIOR OF THE COUPLED ATMOSPHERIC AND OCEANIC BOUNDARY LAYERS IN THE VICINITY OF AN OCEANIC FRONT, PART II: EXPERIMENTAL PLAN	
Steven A. Stage and Robert A. Weller	PO-16

SATELLITE OBSERVATIONS OF SEA SURFACE COOLING BY HURRICANES	
Lothar Stramma, Peter C. Cornillon and James F. Price	PO-16
LARGE DIURNAL SEA SURFACE TEMPERATURE VARIABILITY: SATELLITE AND IN SITU MEASUREMENTS	
Lothar Stramma, Peter C. Cornillon, Robert A. Weller, James F. Price	
and Melbourne G. Briscoe	PO-17

Technical Reports

PROGRAMS FOR COMPUTING PROPERTIES OF COASTAL-TRAPPED WAVES AND WIND-DRIVEN MOTIONS OVER THE CONTINENTAL SHELF AND SLOPE	
Kenneth H. Brink and David C. Chapman	PO-17
MOORED CURRENT METER AND WIND RECORDER MEASUREMENTS NEAR POINT CONCEPTION, CALIFORNIA: THE 1983 OPUS OBSERVATIONS	
Kenneth H. Brink, Dolores H. Chausse and Russ E. Davis	PO-17
LOW-RATE DISCHARGE OF VARIOUS ELECTROCHEMICAL BATTERIES FOR USE WITH OCEANOGRAPHIC INSTRUMENTS	
Alfred J. Ciesluk, Brian J. Guest, Craig D. Marquette and George H. Tupper . . .	PO-17
HYDROGRAPHIC DATA FROM R/V OCEANUS CRUISE 133, LEG VII	
George P. Knapp and Henry M. Stommel	PO-18
MOORED CURRENT METER DATA FROM THE ATLANTIC NORTH EQUATORIAL COUNTERCURRENT NEAR 6°N 28°W (MARCH-OCTOBER 1984) VOL. XXXVII	
Ellen Levy and Philip L. Richardson	PO-18
CODE-2: MOORED ARRAY AND LARGE-SCALE DATA REPORT	
Richard Limeburner, ed.	PO-18
SURFACE DRIFTER MEASUREMENTS IN THE ATLANTIC NORTH EQUATORIAL COUNTERCURRENT 1983-1985	
Philip L. Richardson and Christine M. Wooding	PO-19
HYDROGRAPHIC DATA FROM WARM CORE RING 82-B	
Marvel C. Stalcup, Terrence M. Joyce, R. Lorraine Barbour and Jane A. Dunworth .	PO-19
A COMPILATION OF MOORED CURRENT METER AND WIND RECORDER DATA, VOLUME XXXVIII, LONG-TERM UPPER OCEAN STUDY (LOTUS), (MOORINGS 787, 788, 789, 790, 792) APRIL 1983 - MAY 1984	
Susan A. Tarbell, Ellyn T. Montgomery and Melbourne G. Briscoe	PO-19

TABLE OF CONTENTS

MARINE POLICY AND OCEAN MANAGEMENT PROGRAM	MP-1
INTERNATIONAL OCEAN TRANSPORTATION: PRESENT AND FUTURE	
Bernhard Abrahamsson	MP-3
A SPECIAL MARINE RESERVE FOR THE GALAPAGOS ISLANDS	
James M. Broadus	MP-3
ASIAN PACIFIC MARINE MINERALS AND INDUSTRY STRUCTURE	
James M. Broadus	MP-3
POOR FISH OF REDONDO: MANAGING THE GALAPAGOS WATERS	
James M. Broadus	MP-4
FISHERMEN'S EVALUATIONS OF LIMITED ENTRY: A LONGITUDINAL STUDY OF THE CALIFORNIA ABALONE FISHERY, 1976-1979	
Biliana Cicin-Sain and Maynard E. Silva	MP-4
FISHERIES DEVELOPMENT IN THE THIRD WORLD: THE ROLE OF INTERNATIONAL AGENCIES	
Dean E. Cycon	MP-4
LEGAL AND REGULATORY ISSUES IN UNDERWATER ARCHAEOLOGY	
Dean E. Cycon	MP-5
MANAGING FISHERIES IN DEVELOPING NATIONS: A PLEA FOR APPROPRIATE DEVELOPMENT	
Dean E. Cycon	MP-5
PIRACY AT SEA: THE MODERN CHALLENGE	
Dean E. Cycon	MP-5
PLANNING AND MANAGING BRAZIL'S COASTAL RESOURCES	
Dean E. Cycon	MP-5
WHEN WORLDS COLLIDE: THE EFFECT OF DEVELOPMENT UPON INDIGENOUS PEOPLE	
Dean E. Cycon	MP-5
WHO OWNS THE TITANIC?	
Dean E. Cycon	MP-6
CAN STATES SURVIVE THE THRESHER SHARK CASE?	
Timothy Eichenberg	MP-6
OFFSHORE OIL: ANOTHER CHAPTER	
Timothy Eichenberg	MP-6
ECOLOGY OF THE LOGGERHEAD SEA TURTLE, <u>Caretta caretta</u>	
Nat B. Frazer	MP-6
PROBLEMS IN THE STUDY OF MARINE TURTLES	
Nat B. Frazer	MP-7
SURVIVAL FROM EGG TO ADULTHOOD IN A DECLINING POPULATION OF LOGGERHEAD TURTLES, <u>Caretta caretta</u>	
Nat B. Frazer	MP-7
WIDECAST: HELP FOR CARIBBEAN SEA TURTLES	
Nat B. Frazer	MP-8
A GROWTH CURVE FOR GREEN TURTLES, <u>Chelonia mydas</u> , IN THE DANISH WEST INDIES 1913-1914	
Nat B. Frazer and Rosamund C. Ladner	MP-8
ANNUAL VARIATION IN CLUTCH SIZE AND FREQUENCY FOR LOGGERHEAD TURTLES, <u>Caretta caretta</u> , NESTING AT LITTLE CUMBERLAND ISLAND, GEORGIA, USA	
Nat B. Frazer and James I. Richardson	MP-8
THE GALAPAGOS ISLANDS (ECUADOR): THE USE OF SCIENTIFIC AND TECHNICAL INFORMATION IN COASTAL PLANNING	
Arthur G. Gaines and Efrain Perez	MP-9
INFLUENCE OF FISHERMEN'S PREFERENCES ON THE SUCCESS OF COMMERCIAL FISHERY MANAGEMENT REGIMES	
Michael C. Healey	MP-9
PATENT ACTIVITY IN THE SEABED MINING INDUSTRY	
Porter Hoagland III	MP-10
THE ROLE OF THE U.S. COAST GUARD	
Porter Hoagland III	MP-10
SEABED MINING PATENT ACTIVITY: SOME FIRST STEPS TOWARD AN UNDERSTANDING OF STRATEGIC BEHAVIOR	
Porter Hoagland III	MP-10
SECURITY ASPECTS OF DANISH AND NORWEGIAN LAW OF THE SEA POLICIES	
Finn Laursen	MP-11

ECONOMIC AND OPERATIONAL CONSIDERATIONS OF OFFSHORE DISPOSAL OF SEWAGE SLUDGE	
Thomas M. Leschine and James M. Broadus	MP-11
THE RECRUITMENT AND APPLICATION OF SCIENTIFIC INFORMATION IN COASTAL AND	
MARINE RESOURCES MANAGEMENT: ANALOGS TO THE GALAPAGOS ISLANDS	
Scott McCreary	MP-12
FEEDSTOCK SELECTION FOR SMALL- AND INTERMEDIATE-SCALE FUEL ETHANOL DISTILLERIES	
Mark Meo	MP-12
EXPANSION OF THIRD WORLD NAVIES	
Michael A. Morris	MP-12
SOUTHERN CONE MARITIME SECURITY IN THE POST 1984 TREATY CONTEXT	
Michael A. Morris	MP-13
THE 1984 ARGENTINE-CHILEAN PACT OF PEACE AND FRIENDSHIP	
Michael A. Morris	MP-13
CBMs IN COMPARATIVE PERSPECTIVE: LATIN AMERICA	
Michael A. Morris and Victor Millan	MP-13
AN HISTORICAL PERSPECTIVE ON THE INCIDENCE OF PIRACY	
M. J. Peterson	MP-14
ANTARCTIC IMPLICATIONS OF THE NEW LAW OF THE SEA	
M. J. Peterson	MP-14
ANTARCTIC POLITICS TODAY	
M. J. Peterson	MP-15
GOVERNING THE FROZEN SOUTH: THE ORIGIN AND EVOLUTION OF THE ANTARCTIC TREATY SYSTEM	
M. J. Peterson	MP-15
THE GENERAL ASSEMBLY IN WORLD POLITICS	
M. J. Peterson	MP-16
OCEAN SCIENCE: ITS PLACE IN THE NEW ORDER OF THE OCEAN	
David A. Ross	MP-16
INTERNATIONAL MARINE SCIENCE RESEARCH PROJECTS: INVENTORY AND ANALYSIS OF	
SELECTED PROJECTS AT SEA GRANT INSTITUTIONS--1985	
David A. Ross and Judith Fenwick	MP-17
MARINE AND COASTAL PROTECTED AREAS IN LATIN AMERICA	
Maynard E. Silva and Ingrid DeSilvestre	MP-17
OCEAN RESOURCES AND INTERGOVERNMENTAL RELATIONS: THE RECORD TO 1980	
Maynard E. Silva and Lauriston King	MP-18
THE LOUISIANA RESPONSE TO LAND SUBSIDENCE AND COASTAL EROSION	
Maynard Silva and Mark Meo	MP-18
THE POLITICAL ECONOMY OF THE CITY/STATE INTERFACE	
M. Estellie Smith	MP-18
THE RIGHT TO CHOICE: POWER AND DECISION-MAKING	
M. Estellie Smith	MP-18

TABLE OF CONTENTS

GRADUATE STUDENTS	GS-1
MODERN SEDIMENTATION IN THE NORTHERN BARENTS SEA: INPUT, DISPERSAL, AND DEPOSITION OF SUSPENDED SEDIMENTS FROM GLACIAL MELTWATER	
Stephanie L. Pfirman	GS-3
BENZ(a)ANTHRACENE IN BENTHIC MARINE ENVIRONMENTS: BIOAVAILABILITY, METABOLISM, AND PHYSIOLOGICAL EFFECTS ON THE POLYCHAETE <u>Nereis virens</u>	
Anne E. McElroy	GS-3
THE REACTIVE TRANSPORT OF SUSPENDED PARTICLES: MECHANISMS AND MODELING	
Richard S. Mercier	GS-4
CELL CYCLE CONTROLS IN MARINE PHYTOPLANKTON	
Daniel Vaultot	GS-4
HORIZONTAL AND VERTICAL STRUCTURE OF VELOCITY, POTENTIAL VORTICITY, AND ENERGY IN THE GULF STREAM	
Melinda M. Hall	GS-5
TRANSPORT OF TRACE METALS IN NEARSHORE SEDIMENTS	
William R. Martin	GS-6
PRIMARY PRODUCTION OF PARTICULATE PROTEIN AMINO ACIDS: ALGAL PROTEIN METABOLISM AND ITS RELATIONSHIP TO THE COMPOSITION OF PARTICULATE ORGANIC MATTER	
Steven E. Lohrenz	GS-7
THE GENETIC ANALYSIS OF THE VULVAL CELL LINEAGES OF <u>Caenorhabditis elegans</u>	
Edwin L. Ferguson, Jr.	GS-9
AN INVERSE METHOD FOR OBTAINING THE ATTENUATION PROFILE AND SMALL VARIATIONS IN THE SOUND SPEED AND DENSITY PROFILES OF THE OCEAN BOTTOM	
Subramaniam D. Rajan	GS-9
ESTIMATION OF PLANETARY WAVE PARAMETERS FROM THE DATA OF THE 1981 OCEAN ACOUSTIC TOMOGRAPHY EXPERIMENT	
Ching-Sang Chiu	GS-9
FEEDING HABITS OF THE YELLOWTAIL FLOUNDER AND PRODUCTION OF ITS INVERTEBRATE PREY ON GEORGES BANK	
Jeremy S. Collie	GS-10

DEPARTMENT OF BIOLOGY

Richard H. Backus, Department Chairman

BIOLOGY

ANIMAL PHYSIOLOGY

AND BIOCHEMISTRY

INDUCTION OF CYTOCHROME P-450-DEPENDENT MONOOXYGENASE SYSTEMS IN EMBRYOS AND ELEUTHEROEMBRYOS OF THE KILLIFISH Fundulus heteroclitus

Robert L. Binder, John J. Stegeman
and John J. Lech

Microsomal aryl hydrocarbon hydroxylase (AHH) activity was highly inducible by polychlorinated biphenyls (PCBs) in Fundulus embryos, and stages prior to the appearance of the liver rudiment were competent to respond to these inducers. Consistent with previous observations, basal AHH activity in whole eleutheroembryo microsomes was shown to increase about 9-fold within 24 hrs of hatching. Aminopyrine N-demethylase (APD) activity also increased with time after hatching. However, the increase in APD activity was much less than that of AHH activity, suggesting a posthatching change in basal cytochrome P-450 isozyme composition. Also associated with hatching was an increase in the sensitivity to PCBs as inducers of AHH activity. The ED50 for induction of AHH activity in eleutheroembryos was estimated to be only one-third to one-fourth that in embryos. This developmental increase in the sensitivity to PCBs was not due to a redistribution of PCBs between the yolk and tissues with yolk absorption, and was not simply age-dependent, but appeared to require hatching. An additional change in the MO system associated with hatching was that microsomal NADPH-cytochrome c reductase activity was not inducible by PCBs prior to hatching, but was modestly inducible after hatching.

High performance liquid chromatographic analysis of benzo[a]pyrene (BP) metabolites formed by microsomes from control and PCB-treated eleutheroembryos demonstrated production of dihydrodiols in the 7,8- and 9,10- positions of the benzo-ring. The formation of these metabolites was completely inhibited by the epoxide hydrolase (EH) inhibitor, trichloropropene oxide, indicating the presence of EH in Fundulus eleutheroembryos. Furthermore, these results indicate the Fundulus eleutheroembryos probably can activate BP to its ultimate carcinogenic form, the 7,8-dihydrodiol-9,10-epoxide, and induction of AHH activity by PCBs is likely to increase the rate of formation of activated metabolites from BP and related compounds. However, during

the most active period of organogenesis prior to hatching, basal AHH activity was low and prehatching stages were relatively insensitive to cytochrome P-450 inducers. The combination of these effects may help to protect these stages from damage from activated metabolites.

In press: Chemical-Biological
Interactions.

Supported by: NSF Grant OCE80-18569;
NIEHS Grant ES01080; and NIEHS
Aquatic Biomedical Center Grant
01985.

WHOI Contribution No. 5895.

WARM BRAIN AND EYE TEMPERATURES IN SHARKS

Barbara A. Block and Francis G. Carey

1. Temperatures in the brain and eyes of mako and porbeagle sharks (Lamnidae) are 5°C warmer than the water while the brain and eye temperatures in six other species of pelagic sharks are within 0.1°C of water temperature.
2. An orbital rete mirabile is present in the porbeagle and mako sharks but absent in the cranial vasculature of 16 other species of pelagic sharks.
3. The orbital rete in the head of the porbeagle and mako sharks acts as a heat exchanger which conserves metabolic heat and raises the local tissue temperatures.
4. This brain and eye warming system should insulate the central nervous system from the effects of rapid temperature change. Warming of the retina may improve the visual sensitivity of these active predators.

In press: Journal of Comparative
Physiology.

Supported by: NSF Grants OCE83-11512
and PCM83-08150.

WHOI Contribution No. 6052.

TEMPERATURE, HEAT PRODUCTION AND HEAT EXCHANGE IN LAMNID SHARKS

Francis G. Carey, John G. Casey,
Harold L. Pratt, David Urquhart
and John E. McCosker

Lamnid sharks have an unusual ability to warm their bodies above water temperature. We present the currently available muscle and viscera temperature data for 5 species of these sharks and compare abil-

ity to raise their body temperature. An adequate set of temperature data is available for the short fin mako, but only a few measurements have been made on the other lamnids. Because these sharks are difficult to obtain, and when caught, are often in poor condition, further temperature data will accumulate only slowly. We therefore supplement the temperature measurements with information on anatomical features related to metabolic heat production and heat conservation. These include relative heart size, the amount and distribution of red muscle, the number of vessels in the lateral cutaneous rete, and the weight of the suprahepatic rete relative to that of the visceral mass it serves. From this anatomical information we rank the sharks: Isurus paucus, I. oxyrinchus, Carcharodon carcharias, Lamna nasus, L. ditropis, in order of an increasing ability to elevate their temperatures. This ranking is consistent with the existing temperature data. We also note a relationship of muscle temperature to environmental temperature, with the greatest elevations in body temperature found in sharks from the coldest water.

Published in: Memoirs, Vol. 9,
92-108, 1985.

Supported by: NSF Grants OCE83-11512
and PCM83-08150.

WHOI Contribution No. 6123.

GLUCOSE TRANSPORT BY THE IN VITRO
PERFUSED MIDGUT OF THE BLUE CRAB,
Callinectes sapidus I. TRANSMURAL FLUXES

Ka Hou Chu

Nutrient absorption is an important function of the gut of animals. The mechanisms of nutrient absorption in mammalian intestine have been extensively investigated (see Code, 1968 for review). These studies led to the formulation of the well-known Na^+ -gradient hypothesis (see Schultz & Curran, 1970; Crane, 1977; Schultz, 1977 for reviews). Relatively little is known concerning the nutrient absorptive processes in the gut of invertebrates. In crustaceans, the foregut and hindgut, lined with a cuticle, are generally considered to be of little importance in nutrient uptake. The principal site of absorption is believed not to be in the tubular midgut but in the hepatopancreas (see Gibson & Barker, 1979; Dall & Moriarty, 1983 for recent reviews). During the last decade, a number of reports on nutrient transport mechanisms in the crustacean midgut have appeared (Ahearn,

1974, 1976; Ahearn & Maginniss, 1977; Brick & Ahearn, 1978; see Ahearn, 1982 for a review). These studies showed that the crustacean midgut exhibits many of the basic transport characteristics of mammalian intestine, such as Na^+ -dependency and saturation behavior. Kinetic evidence, however, indicated that the midgut does not play a major role in nutrient uptake. There have been no other nutrient transport studies on crustacean midgut.

Supported by: NOAA Grant NA80AA-
D-00077 (R/P-8) and WHOI Ocean
Industry Program.

WHOI Contribution No. 6020.

GLUCOSE TRANSPORT BY THE IN VITRO
PERFUSED MIDGUT OF THE BLUE CRAB,
Callinectes sapidus RATHBUN II.
MUCOSAL UPTAKE

Ka Hou Chu

There are numerous studies dealing with the digestive functioning of the crustacean gut (see Dall & Moriarty, 1983 for a review), but relatively little work has been done on the nutrient absorptive process. Recent studies on transport processes in the crustacean gut have been reviewed by Ahearn (1982). Most investigations on the mechanisms of nutrient uptake have been directed at the tubular midgut (Ahearn, 1974, 1976; Ahearn & Maginniss, 1977; Brick & Ahearn, 1978). These studies showed that whereas the tissue has many transport properties in common with the mammalian intestine, its role in nutrient absorption may be limited. This notion has been supported by my previous study on transmural glucose absorption across the isolated midgut of the blue crab, Callinectes sapidus (Chu, 1985). I have shown that most glucose translocated across the midgut is in the form of free glucose, and glucose transport in this tissue is energy and Na^+ -dependent and exhibits saturation kinetics. Moreover, the presence of a Na^+ -dependent phlorizin-sensitive mucosal uptake mechanism was suggested. The present investigation was performed to clarify the mucosal glucose uptake step in the same preparation. Kinetic studies confirm the presence of a Na^+ -dependent phlorizin-sensitive saturable mechanism for glucose transport across the mucosal border. A Na^+ -independent, apparently diffusive, pathway is also involved. Further, glucose entering the midgut appears predominantly as phosphorylated forms, suggesting that efflux of free glucose across the serosal border requires an active mechanism.

Supported by: NOAA Grant NA80AA-D-00077 (R/P-8) and WHOI Ocean Industry Program.

WHOI Contribution No. 6021.

GROWTH AND SURVIVAL OF LARVAE OF
Mercenaria mercenaria (L.) AND
Crassostrea virginica (Gmelin) RELATIVE
TO BROODSTOCK CONDITIONING AND
LIPID CONTENT OF EGGS

Scott M. Gallagher and Roger Mann

Artificial conditioning of broodstocks of Mercenaria mercenaria and Crassostrea virginica (Gmelin) were initiated at various times throughout the year under both laboratory and commercial hatchery conditions. Attempts were made to spawn broodstocks at weekly intervals while data was collected on the initial total egg lipid content of eggs by analytical procedures and by visual inspection after staining with Oil Red O. The physical parameters of egg diameter and density (estimated by density gradient centrifugation) were correlated with egg lipid content. Significant correlations were evident between the initial egg lipid content and survival to both straight hinge (24 hrs) and pediveliger stages ($p < 0.01$); however, egg lipid content did not correlate with subsequent larval growth rate. A characteristic of high survival to the straight hinge stage (i.e., $> 75\%$) was catabolism of a minimum of about 4.5 ng total lipid during the embryonic stages (i.e., fertilization through to prodissoconch I shell formation) in both bivalve species. Good survivorship to the pediveliger stage (i.e., $> 1\%$) was always predicated by eggs containing a minimum of 12% lipid of the ash free dry weight (AFDW), however, relatively high lipid levels did not guarantee good larval survival. Species specific egg density profiles were clearly evident; eggs of C. virginica banded unimodally at $1.075 \text{ g} \cdot \text{cm}^{-3}$ while eggs of M. mercenaria banded trimodally at 1.038, 1.059 and $1.073 \text{ g} \cdot \text{cm}^{-3}$. Egg lipid was logarithmically related to egg diameter. The data suggest that there is a minimum, size related threshold lipid level in eggs necessary for optimal survival through the non-feeding embryonic stages; but environmental or genetic factors other than egg lipid content are responsible for a considerable fraction of the mortality during this period. Variations in the broodstock conditioning protocol induced large fluctuations in egg lipid levels, suggesting that strict attention should be paid to conditioning if optimal culture potential is desired. Minor variations in egg lipid

levels (i.e., 4-8% AFDW) were visually discernible by staining with Oil Red O in both laboratory and hatchery environments. Evaluating eggs at the time of spawning for their potential for survival using the lipid staining technique can provide valuable real-time information for both research and commercial hatchery applications.

Supported by: NOAA, Office of Sea Grant, Grant NA80AA-D-00077 and ONR Contract N00014-82-C-0019, NR 083-004.

WHOI Contribution No. 5921.

INDIVIDUAL VARIABILITY IN LIPID CONTENT
OF BIVALVE LARVAE QUANTIFIED
HISTOCHEMICALLY BY ABSORPTION PHOTOMETRY

Scott M. Gallagher and Roger Mann

Lipid energy reserves in individual larvae of the Teredinid bivalve, Bankia gouldi (Bartsch), were quantified photodensitometrically after staining whole larvae with the lipid specific stain, Oil Red O. A modification of the two wavelength densitometric technique of Mendelson (1966) was used to document variability in stored lipid in healthy larvae and larvae under imposed nutritional stress. The results were compared with analytically derived total lipid values for the same larval samples. A third wavelength was added to the two-wavelength technique to allow direct background subtraction of tissue and shell absorbance on individual larvae. Lipid content in individual larvae were estimated photodensitometrically to range from a mean of 7 ng in three-day-old straight-hinge larvae to 175 ng in pediveliger larvae which were competent to metamorphose. During starvation, pediveliger larvae lost lipid at a rate of about $20 \text{ ng} \cdot \text{day}^{-1}$ while a loss of $1-2 \text{ ng} \cdot \text{day}^{-1} \cdot \text{larva}^{-1}$ was evident in six-day-old early umbo larvae. Variability in lipid content between individuals of the population was analyzed by frequency histogram and by the product of the third moment to detect abnormal distribution about the mean, i.e., skewness. Although the variability was high in healthy larvae (e.g., for 18-day-old larvae: mean, $x = 60.5 \text{ ng lipid} \cdot \text{larva}^{-1}$, coefficient of variation, $CV = 61\%$), it increased substantially during starvation (e.g., for 18 + 6 days starvation: $x = 11.8$, $CV = 197\%$). Starvation caused the lipid content of individuals to become highly negatively skewed with respect to the population mean (i.e., more individuals fell

below rather than above the mean). The magnitude and direction of skewness away from the mean proved to be a more timely and sensitive indicator of physiological stress than considering mean or standard deviation parameters alone. It is suggested that analysis of lipid energy stores of individuals within zooplankton populations may provide valuable insight into the capacity of natural assemblages to cope with stress, be it chemical, thermal, physical, or biological in nature.

In press: Journal of Plankton Research.

Supported by: ONR Contract N00014-82-C-0019, NR 083-044; NOAA, Office of Sea Grant, Grant NA80AA-D-00077; and NSF Grant OCE83-09558.

WHOI Contribution No. 5920.

LIPID AS AN INDEX OF GROWTH AND VIABILITY IN THREE SPECIES OF BIVALVE LARVAE

Scott M. Gallagher and Roger Mann

The larvae of three species of bivalve molluscs, Crassostrea virginica (Gmelin), Ostrea edulis (L.), and Mercenaria mercenaria (L.) were reared under a variety of temperature and food species regimes in the laboratory. Data were collected on growth (shell length and height), survival (fertilization through one week post-settlement), total lipid content, and lipid class composition of both healthy larvae and larvae that were removed from culture and starved for a three to four-day period. Subsamples were stained specifically for lipid content with the lipid specific stain Oil Red O. Newly formed straight-hinge larvae of all three species visually exhibited small lipid droplets dispersed throughout the tissues. These were resorbed within four days of the initiation of feeding while the digestive gland filled with exogenously supplied lipid. Embryogenesis took place at the expense of 69 and 71% of parentally derived total lipid (M. mercenaria and C. virginica, respectively), 92.8 and 68.3% of which was composed of triacylglycerols (M. mercenaria and C. virginica, respectively). After eight days of feeding on Isochrysis aff. galbana (clone T-ISO), total lipid had increased 2.7 fold in larvae of C. virginica grown at 25°C, 37.6 fold in larvae of M. mercenaria grown at 22°C, and 1.7 fold in larvae of O. edulis grown at 25°C. Shell growth in larvae of C. virginica grown at 30°C was initially higher than that at 25°C, but lipid was accumulated 2.5 times slower and survival of pediveliger larvae through metamorphosis was

considerably reduced at this elevated temperature. The lipid class composition of healthy larvae of C. virginica and M. mercenaria was dominated by triacylglycerols and phospholipids in approximately equal proportions; however, triacylglycerols were preferentially catabolized during starvation and were responsible for greater than 80% of the total lipid loss. A series of color photographs of larvae stained with Oil Red O are presented that illustrate lipid levels in developing larvae in both healthy and poor condition. From these, a visual index of lipid content was developed to allow comparisons between larval survival and lipid levels. In general, high survival was always accompanied by a high lipid index but a high lipid index did not guarantee good survival. We suggest that the lipid index may be used to visually document the lipid content in individual bivalve larvae as an indicator of physiological condition and potential for successful metamorphosis.

Supported by: NOAA, Office of Sea Grant, Grant NA80AA-D-00077 and ONR Contract N00014-82-C-0019, NR 083-004.

WHOI Contribution No. 5919.

IN VIVO METABOLISM OF BENZ(a)ANTHRACENE BY THE POLYCHAETE Nereis virens

Anne E. McElroy

Polycyclic aromatic hydrocarbons (PAH) can be metabolically activated to reactive intermediates with mutagenic potential. Although marine sediments serve as the major repository for PAH released into the environment, little is known of the capabilities of benthic organisms, particularly infaunal invertebrates to metabolize PAH¹. In this study, in vivo metabolism of the PAH benz(a)anthracene (BA) by the polychaete Nereis virens was investigated. Worms maintained in flow-through benthic microcosms were exposed to [¹⁴C-12]-BA sorbed to sediment, introduced directly to the water column, and to labeled food for periods of 4 to 25 days. Regardless of mode of exposure, most radiolabel recovered from Nereis was present as metabolic products with only 2 to 23% remaining as parent compound. In addition, a significant proportion (from 33 to 51%) of accumulated radioactivity was neither solvent extractable nor water soluble, suggesting that incorporation into macromolecular pools is a major fate of accumulated BA in Nereis virens.

In press: Marine Environmental Research, Special Issue Responses of Marine Organisms to Pollutants, Vol. 17, 1985.

Supported by: NOAA Grant 83-ABD-00012; NWF/API Environmental Conservation Fellowship; and WHOI Coastal Research Center Grant.

WHOI Contribution No. 5986.

NUTRITIONAL AND BIOENERGETIC
CONSIDERATIONS IN THE EARLY DEVELOPMENT
OF THE AMERICAN LOBSTER
Homarus americanus MILNE EDWARDS

Glenn C. Sasaki, Judith M. Capuzzo
and Patricia Biesiot

To better understand critical periods in the early life history stages of the American lobster Homarus americanus, physiological and biochemical aspects of development have been investigated. These studies focused specifically on key transitional periods between extrusion of the eggs and post-metamorphosis of the larval form - i.e., early and late embryonic periods, hatching, larval development, molting, metamorphosis, and attainment of the postlarval stage. Biochemical changes during embryogenesis reflect the catabolism of various substrates for energy demands. Considerable variation in the rate of utilization of energy substrates during embryogenesis are observed at different temperatures. Embryos raised at elevated temperatures have increased amounts of yolk remaining at the time of hatching; these yolk remnants can serve as a supplemental energy store during the early posthatch period and may delay the initiation of first-feeding. The first three larval stages are similar in their preference for energy substrates, with lipid being of primary importance, and the turnover rate for lipid can be quite rapid. Weight-specific metabolic rates increase with each successive larval stage. In post-metamorphic stage IV larvae, the dependency on lipid as an energy substrate for immediate metabolic demands is diminished and lipid reserves serve a long-term storage function. Metabolic rates of premolt stage IV larvae are also decreased in comparison to earlier stages. These changes in physiology correlate with changes in the developing digestive gland (hepatopancreas) and specifically with the first appearance of lipid droplets in the lipid-storing cells of stage IV larvae. By attainment of stage VI, postlarval lobsters have energy storage and metabolic patterns similar to

the adult, as well as adult digestive gland morphology. The transitions from hatching to metamorphosis and to attainment of the postlarval form and selection of a benthic habitat are reflected in differences in physiological and biochemical processes that influence food selection and dietary patterns. Understanding such patterns are important to assessing the feeding requirements of early stages of the lobster in its natural habitat.

Supported by: MIT/WHOI Joint Program in Oceanography; WHOI Ocean Industries Program; the Tai Ping Foundation; the U.S. Department of Interior, Bureau of Land Management Contract No. AA551-CT9-5; and NOAA, Office of Sea Grant, Grant NA80-AA-D-00077 (RP-5; RP-11).

WHOI Contribution No. 6041.

BENZO[a]PYRENE OXIDATION AND MICROSOMAL
ENZYME ACTIVITY IN THE MUSSEL (Mytilus
edulis) AND OTHER BIVALVE MOLLUSC
SPECIES FROM THE WESTERN N. ATLANTIC

John Stegeman

Analysis of subcellular fractions revealed a complement of microsomal electron transport components including reductases and heme proteins in several organs of three bivalve species, Mytilus edulis, Macrocalista maculata and Arca zebra. Dithionite difference spectroscopy of CO-ligated microsomes yielded spectra typical of cytochrome P-450 in digestive gland and gill, with absorption maxima at 450 nm. A time dependent reduction of cytochrome P-450 was also observed. The levels of these components and rates of microsomal benzo[a]pyrene metabolism were highest in the digestive gland and were very similar between species. In Mytilus edulis, there was a suggested seasonal variation in B[a]P metabolism but no population differences in this activity or in levels of other components, suggesting minimal regulation by environmental chemicals. Digestive gland microsomal metabolites of BP identified by HPLC retention and UV spectroscopy included BP-1,6-quinone, BP-3,6-quinone, and BP-6,12-quinone, which equalled 65% of the total metabolites, and dihydrodiols and phenols, the latter products consistent with cytochrome P-450 monooxygenation and epoxide hydrolase function. However, the inconsistent dependence of BP metabolism on NADPH and inconsistent inhibition by CO suggest catalyst(s) additional to cytochrome P-450 may be acting in BP metabolism. Based on these results and the prominent quinone

formation, we speculate that such action involves some peroxidative mechanism(s). The role of peroxidative as well as monooxygenase reactions on the in vivo disposition and effects of chemicals in bivalves, and also the major function of cytochrome P-450 in these animals, remain to be established.

Published in: Marine Biology, 89,
21-30, 1985.

Supported by: NOAA, Office of Sea
Grant, Grant NA80AA-D-00077; NSF
Grants OCE80-18569 and OCE83-
10505; and Exxon Fellowship at the
Bermuda Biological Station.

WHOI Contribution No. 5889.

METHODS FOR ANALYSIS OF MONOOXYGENASE SYSTEMS IN MARINE FISH

John J. Stegeman

Cytochrome P-450-dependent monooxygenases play a major role in the biotransformation or metabolism of myriad organic xenobiotics, such as pesticides, hydrocarbons, chlorinated hydrocarbons, and numerous biological molecules, including steroid hormones. The metabolism of both xenobiotics and endogenous substrates can result either in activation or inactivation of these substrates, with quite different consequences for an organism. Thus, the metabolism of the environmental procarcinogen benzo[a]pyrene, as a well known example from mammalian studies, can on one hand result in more rapid elimination of the compound, but at the same time may form the active carcinogenic derivatives of this compound. The biological roles of monooxygenases indicate an important involvement in the effects of environmental chemicals in fish, including the likelihood that the neoplasms occurring in fish in various regions manifest an activity of cytochrome P-450 in activating carcinogens. A broad objective of studying monooxygenase systems in marine animals is to understand the mechanisms of biotransformation and their role in detoxication, toxication, and effects of pollutants.

This chapter provides in detail methods for analysis of monooxygenases in fish, including methods developed in the author's laboratory, as a guide to those undertaking research in this area. The application and interpretation of results with specific catalytic and immunochemical probes are discussed.

In press: "Strategies in Marine

Pollution Studies," CRC Press,
1986.

Supported by: NSF Grants OCE80-18569
and OCE83-10505.

WHOI Contribution No. 5899.

INDIVIDUAL VARIATION IN PATTERNS OF BENZO[a]PYRENE METABOLISM IN THE MARINE FISH SCUP (Stenotomus chrysops)

John J. Stegeman and Margaret O. James

The metabolism at specific sites on carcinogenic hydrocarbons such as benzo[a]pyrene (BP) is responsible for activation to the ultimate mutagens and carcinogens, and patterns of metabolism can thus influence the biological effect of such compounds. Marine fish are known to efficiently metabolize BP at the benzo-ring, forming high percentages of the 9,10-dihydrodiol (DHD) and 7,8-DHD, the latter including the penultimate carcinogen. Such metabolism is presumably related to the efficient activation of BP by fish and possibly to environmental carcinogenesis by polynuclear aromatic hydrocarbons (PAH). Hydrocarbon-induced cytochrome P-450 in fish is known to be responsible for initiating metabolism on the benzo-ring, but epoxide hydrolase (EH) activity is required for DHD formation. Both factors could influence formation of the DHD leading to the ultimate carcinogenic diol-epoxide. In the present study, patterns of BP metabolism were evaluated in a number of individual scup, Stenotomus chrysops, sampled from local Woods Hole waters, and a correlation described between variation in DHD formation and native EH activity in those feral fish.

In press: Marine Environmental
Research.

Supported by: NSF Grants OCE80-18569
and OCE83-10505.

WHOI Contribution No. 5932.

MONOOXYGENASE INDUCTION AND CHLOROBIPHENYLS IN THE DEEP SEA FISH Coryphaenoides armatus

John J. Stegeman, Pamela J. Kloepper-Sams
and John W. Farrington

Inhibition of hepatic microsomal ethoxyresorufin O-deethylase and aryl hydrocarbon hydroxylase activities in the deep-sea fish Coryphaenoides armatus by α -naphthoflavone and by polyclonal anti-

bodies (anti-P-450E) specific to hydrocarbon-inducible cytochrome P-450 from teleost liver indicated xenobiotic-induced origin of these activities. Specific recognition of a protein by anti-P-450E in an immunoblot further indicated a xenobiotic-induced catalyst. Levels of apparently induced P-450 and monooxygenase activity correlated positively with tissue content of chlorobiphenyls of known inducing activity, implicating such compounds in biochemical effects in the deep ocean.

In press: Science.

Supported by: NSF Grants OCE80-18569 and OCE83-10505; NOAA Grant WASC83-00220; and WHOI Mellon Foundation Award.

WHOI Contribution No. 6014.

MICROSOMAL CYTOCHROME P-450 FUNCTION IN FISH EVALUATED WITH POLYCLONAL AND MONOCLONAL ANTIBODIES TO CYTOCHROME P-450E FROM SCUP (*Stenotomus chrysops*)

John J. Stegeman, Bruce R. Woodin, Sang S. Park, Pamela J. Kloepper-Sams and Harry V. Gelboin

Monooxygenase reactions catalyzed by cytochromes P-450 are paramount in the oxidative metabolism of many xenobiotics, determining both the persistence and effects of numerous types of compounds. Evaluating the spectrum of catalytic functions associated with specific isozymes in microsomes could indicate the contribution to xenobiotic metabolism and disposition or, conversely, toxication of specific compounds in a given species. Immunological probes are proving useful in evaluating the functions of P-450 isozymes in microsomal preparations from many species. Regulation of specific isozymes by endogenous and exogenous factors can also be evaluated with such probes. Specific probes might thus provide explicit evidence for induced P-450 in fish, to indicate that certain types of compounds are present in a given environment at biochemically significant levels. We here describe studies on the activities apparently catalyzed by induced P-450 in fish, evaluated with both polyclonal and monoclonal antibodies to cytochrome P-450E, the apparent major β -naphthoflavone (BNF) or methycholanthrene (MC)-inducible isozyme purified from scup. There was extensive cross-reactivity indicated by parallel patterns of enzyme inhibition in several fish species, including rainbow trout, brook trout, and

blue-striped grunt, but not with rat. The results suggest extensive homology among PAH inducible cytochromes P-450's in teleost fish.

In press: Marine Environmental Research.

Supported by: NSF Grants OCE80-18569 and OCE83-10505.

WHOI Contribution No. 5931.

B E N T H O S

HYDROTHERMAL VENT ANIMALS: DISTRIBUTION AND BIOLOGY

J. Frederick Grassle

Hydrothermal vent communities characterized by large clams, mussels, and vestimentiferan worms thrive on chemosynthetic microbial production. There are similarities in the animal distributions at vent communities from 20°S to 46°N in the Pacific Ocean and at cold sulfide seeps in the Gulf of Mexico. Vent communities are at least 200 million years old. Since the life-span of a vent is only tens of years, the species survive by rapid growth and widespread dispersal of larvae with the subsequent colonization of new vents.

Published in: Science, 229, 713-717, 1985.

Supported by: NSF Grants OCE78-10458, OCE78-10459, OCE81-15251 and OCE83-11201.

WHOI Contribution No. 5963.

THE ECOLOGY OF DEEP SEA HYDROTHERMAL VENT COMMUNITIES

J. Frederick Grassle

"The internal heat of a planet, mostly of radioactive origin, in theory would provide an alternative to incoming radiation though we have little precedent as to how an organism could use it." (Hutchinson, 1965, p. 3). Hydrothermal vents, first discovered in 1977 at 2500 m depth on the Galapagos Rift, provide an example of such an alternative ecosystem supported by chemosynthetic primary production. Hydrothermal fluid pouring from the cracks, crevices, and chimneys in the sea floor supports large numbers and kinds of bac-

teria capable of deriving energy from reduced compounds such as hydrogen sulfide. This life-supporting fluid is the result of sea water circulating deep within porous basalts and reacting at high temperatures with the rock from magma chambers along ridge axes where new sea floor is being formed. Large clusters of red-plumed worms, Riftia pachyptila Jones 1980, emerging from 2-3 m long, thick, white tubes give an other-worldly appearance to the rich community of animals sustained by the bacteria. These thermal oases contrast sharply with the surrounding relatively barren rock surfaces. The dense communities of worms, clams and mussels have a weight of living tissue exceeding 20-30 kg/m² (combined wet weight biomass of the two most common species -- Childress quoted by Somero et al., 1983; Hessler and Smithey, 1983; Laubier and Desbruyeres, 1984).

In press: Advances in Marine Biology.

Supported by: NSF Grants OCE78-10458, OCE78-10459, OCE81-15251 and OCE83-11201.

WHOI Contribution No. 5987.

B I O G E O G R A P H Y A N D S Y S T E M A T I C S

CIRCULATION AROUND ISLANDS AND THE DISPERSAL OF PLANKTONIC LARVAE

Mary W. Farmer and Carl J. Berg, Jr.

Oceanic circulation around islands influences the dispersal of planktonic larvae and the recruitment of juveniles to islands. Six models of hydrographic effects related to circulation at island boundaries are presented: 1) "diffusion" in a stratified sea, 2) plumes due to tidal oscillation, 3) seasonal convergence zones, 4) eddies impinging on the island but generated away from it, 5) upwelling generated near the island, and 6) eddies generated by the topography of the island. The degree to which reproductive patterns of organisms with planktonic larvae are synchronized with circulation patterns such as these will affect their large-scale distribution, gene flow, and evolution.

Supported by: Sea Education.

WHOI Contribution No. 6092.

TOWARD A STUDY OF THE BIOGEOGRAPHY OF PELAGIC CTENOPHORES

G. Richard Harbison

Pelagic ctenophores are rarely found in collections made with nets, yet collections made by SCUBA divers reveal an extremely rich epipelagic fauna, and collections made with submersibles reveal an even more extensive midwater fauna. Ctenophores and other fragile gelatinous organisms have been shown to be of central importance in determining the distribution patterns of hyperiid amphipods, proving that biotic as well as physical factors must be taken into account in pelagic biogeography. Improvements in the ability to sample these organisms and to study them in situ are essential for future progress.

In press: Proceedings International Conference on Pelagic Biogeography. A. C. Pierrot-Bults, R. K. Johnson, S. van du Spoel and B. J. Zahuranec, eds. UNESCO, Paris.

Supported by: NSF Grant OCE84-00243.

WHOI Contribution No. 6064.

THE APLACOPHORAN FAMILY PROCHAETODERMATIDAE IN THE NORTH AMERICAN BASIN, INCLUDING Chevroderma n.g. AND Spathoderma n.g. (MOLLUSCA; CHAETODERMOMORPHA)

Amelie H. Scheltema

Six species in three genera of Prochaetodermatidae are described from over 650 stations and 5,200 specimens in the Atlantic and north Pacific Oceans from depths between 500 and 7,300 m. Included are all species in the North American Basin and all species in Chevroderma n.g.

Three principal characters differentiate prochaetodermatid species and genera: spicules, radula, and body shape. Family membership is defined by radula and jaws. Spicule morphology determines genus, and species are described by spicules and radula. Mean body shape describes populations of species. Interference colors produced by the aragonite spicules indicate spicule thickness and symmetry. The variation in Prochaetoderma yongei n.sp., described in detail, establishes the taxonomic base on which to judge the morphological limits of a prochaetodermatid species.

Spathoderma n.g. and Chevroderma n.g. differ from each other and from the genus Prochaetoderma in spicule morphology. P. yongei and S. clenchi n. sp. are wide-

spread northwestern and eastern Atlantic continental slope and abyssal rise species. C. turnerae and C. gausson n. spp. are abyssal species, the former occurring throughout the Atlantic, the latter only in the northern West European Basin. C. scalpellum n. sp. is a slope species of restricted range in the eastern Atlantic. C. whitlatchi n. sp. is a wide-ranging abyssal and hadal species of the northern east and mid-Pacific. A wide geographic range is correlated with a vertical depth distribution greater than 1,500 m.

All species are patchy in distribution but particular species can be numerically dominant and occur at high densities locally, e.g., up to 400 m⁻² for P. yongei and 178 m⁻² for C. whitlatchi. In the north Atlantic, greatest numerical abundances and lowest diversity of Prochaetodermatidae occur in the North American Basin.

Published in: Biological Bulletin,
169, 484-529, 1985.

Supported by: NSF Grants GB6027X,
GA31105, GA36554, DES74-22339,
OCE76-21968, OCE78-19820 and
OCE81-17586; EPA Order WA-6-99-
3177-A; and ONR Contract
N00014-74-C0262, NR 083-004.

WHOI Contribution No. 5930.

E C O S Y S T E M S T U D I E S

RIVERINE SYSTEMS

STRUCTURE AND FUNCTION IN A BENTHIC INVERTEBRATE STREAM COMMUNITY AS INFLUENCED BY BEAVER (Castor canadensis)

Donald M. McDowell and Robert J. Naiman

Beaver (Castor canadensis) affect the benthic invertebrate community of small woodland streams in Quebec through habitat modifications. Their activities influence community structure through the replacement of lotic taxa by lentic forms and community function by increasing the absolute importance of collectors and predators while decreasing the relative importance of shredders and scrapers in impounded sites. At our study site during the 1983 ice-free season, standing stocks of coarse particulate organic matter (< 1 mm) were 2-5 times greater ($P < 0.05$) in impounded sites in all seasons. Chlorophyll α standing stocks did not differ statisti-

cally among sites. Total density and biomass of invertebrates in impoundments were 2-5 times greater ($P < 0.05$) in unaltered sites in autumn. Nonimpounded sites were dominated by Simuliidae, Tanytarsini chironomids, scraping mayflies, and net spinning caddisflies while impounded sites were characterized by Tanypodinae and Chironomini chironomids, predacious odonates, Tubificidae, and filtering pelycospods. Our results suggest that current paradigms applied to lotic ecosystems need to be reevaluated to incorporate the influence of beaver upon invertebrate communities.

In press: Oecologia.

Supported by: NSF Grant DEB81-05677.

WHOI Contribution No. 6022.

ANADROMOUS BROOK TROUT, Salvelinus fontinalis: OPPORTUNITIES AND CONSTRAINTS FOR POPULATION ENHANCEMENT

Robert J. Naiman, Stephen D. McCormick,
W. Linn Montgomery and Roderick Morin

We present an overview and an evaluation of studies conducted between 1978 and 1984 on anadromous brook trout (Salvelinus fontinalis) near Sept-Îles, Quebec. We integrate studies on experimental sea ranching with those on the life history and osmoregulatory physiology of anadromous stocks, compare our results with those reported for other anadromous and nonanadromous stocks, and place our conclusions in an historical, economical and social perspective. We suggest that anadromous brook trout, and possibly other members of the genus Salvelinus, are reasonable candidates for local enhancement of coastal or estuarine salmonid fisheries in northern latitudes. Salvelinus exhibits short but synchronized migratory movements, they remain in coastal waters, they have rapid growth while at sea, they have a well-developed homing ability, they have an ability to enter brackish water at a small size, and they provide a potentially high yield to recreational and commercial fisheries. Applied research is the key for developing a relatively low effort, high yield coastal fishery with the economic gains accruing to populations of rural areas.

Supported by: Matamek Research Program
of WHOI; WHOI Education Program;
and le Ministère du Loisir, de la
Chasse et de la Pêche du Québec.

WHOI Contribution No. 5957.

SALT MARSH SYSTEMS

TIDAL FLUSHING OF AN ESTUARINE EMBAYMENT SUBJECT TO RECURRENT DINOFLAGELLATE BLOOMS

Veronique C. Garcon, Keith D. Stolzenbach
and Donald M. Anderson

A rhodamine dye tracer study was conducted over eight tidal cycles to investigate mixing and tidal exchange processes in Perch Pond, a Cape Cod embayment subject to recurrent blooms of the toxic dinoflagellate, Gonyaulax tamarensis. Dye injected at the inlet to Perch Pond during flood tide became well-mixed within the pond in one day and was removed at an effective first order rate of $.36 \text{ day}^{-1}$, equivalent to a 70 percent utilization of the maximum possible tidal exchange. This relatively high flushing efficiency can be attributed to a density driven circulation within the pond consisting of a subsurface inflow of high salinity dense water on the flood tide followed by removal of lighter surface layers through the shallow inlet during ebb tide. The formation of a frontal convergence near the inlet on flood tide is consistent with the observed distribution of G. tamarensis cysts and shellfish toxicity. More importantly, it is clear that phytoplankton like G. tamarensis whose maximum growth rates approximate the rate of tidal flushing can only bloom within the embayment by avoiding the outflowing surface waters. This is presumably accomplished by a restricted vertical migration. Blooms of G. tamarensis may be limited by advective losses during dry periods when the pond salinity is higher and the stratification weaker.

Supported by: NOAA, Office of Sea Grant, Grants NA81AA-D-00069 and NA81RA-D-0012.

WHOI Contribution No. 5950.

F I S H

ENCOUNTER WITH A SWORDFISH (Xiphias oladius) AND SHARPTAIL MOLA (Masturus lanceolata) AT A DEPTH GREATER THAN 600 METERS

John Janssen and G. Richard Harbison

On one night of diving with the submersible, Johnson-Sea-Link II, a large Xiphias gladius and a Masturus lanceolatus

were encountered at depths exceeding 600 m. The swordfish sighting occurred two hours after sunset, suggesting that the fish had failed to make its nightly upward migration. The ocean sunfish sighting suggests that this fish may be a permanent member of the midwater community, since surface sightings are so rare. The abundance of gelatinous animals at these depths adds weight to this speculation.

Supported by: NSF Grant OCE84-00243.

WHOI Contribution No. 5922.

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

SHORT-TERM ENDPRODUCTS OF SULFATE REDUCTION: FORMATION OF ACID VOLATILE SULFIDES, ELEMENTAL SULFUR AND PYRITE

Gary M. King, Brian L. Howes
and John W. H. Dacey

Rates of sulfate reduction, oxygen uptake and carbon dioxide production in sediments from the short Spartina alterniflora region of Great Sippewissett Marsh were measured simultaneously during late summer. Surface sediments (0-2 cm) were dominated by aerobic metabolism which accounted for 51% of the total carbon dioxide production over 0-15 cm. Rates of sulfate reduction agreed well with rates of total carbon dioxide production below 2 cm depth indicating that sulfate reduction was the primary pathway for sub-surface carbon metabolism. Sulfate reduction rates were determined using a radiotracer technique coupled with a chromous chloride digestion and carbon disulfide extraction of the sediment to determine the extent of formation of radiolabelled elemental sulfur and pyrite during short-term (48 hr) incubations. In the surface 10 cm of the marsh sediments investigated, about 50% of the reduced radiolabeled sulfur was recovered as dissolved or acid volatile sulfides, 37% as elemental sulfur, and only about 13% was recovered in a fraction operationally defined as pyrite. Correlations between the extent of sulfate depletion in the marsh sediments and the concentrations of dissolved and acid volatile sulfides supported the results of the radiotracer work. Our data suggests that sulfides and elemental sulfur may be major short-term end-products of sulfate reduction in salt marshes.

Published in: *Geochimica et Cosmochimica Acta*, GCA49, 1561-1566, 1985.

Supported by: NSF Grant BSR83-08800.

WHOI Contribution No. 5855.

M A R I N E M A M M A L S

THE USE OF PHOTOGRAPHS TO IDENTIFY INDIVIDUAL NORTH ATLANTIC RIGHT WHALES (*Eubalaena glacialis*)

Scott D. Kraus, Karen E. Moore, Carol A. Price, Martie J. Crone, William A. Watkins, Howard E. Winn and John H. Prescott

Photographic techniques for identifying individual North Atlantic right whales (*Eubalaena glacialis*) were investigated. The effects of differences between aerial and shipboard photography were indicated and related to cataloging and matching methods. Photographs of known female right whales were compared, using the collections of Woods Hole Oceanographic Institution (photos from 1956-1983), University of Rhode Island (1973-1984), New England Aquarium (1973-1984), and Center for Coastal Studies (1979-1984). Matches of photographs of individual right whale cows provided information on distribution and minimum calving intervals. The stability of individually identifiable features over time was analyzed in the New England Aquarium's collection, demonstrating that some features such as callosity outline could change, while others, such as ventral white patches and lip crenations, appeared stable over at least the seven years compared. Suggestions were made for collecting, analyzing, and interpreting future right whale photographs.

Supported by: National Marine Fisheries Contract 50-EANF-5-00068.

WHOI Contribution No. 6073.

THE INTERNATIONAL CODE OF ZOOLOGICAL NOMENCLATURE AND A PARADIGM: THE NAME *Physeter catodon* LINNAEUS 1758

William E. Schevill

This is a critical notice of the third edition of the International Code of Zoological Nomenclature, 1985, and a deter-

mination that the valid technical name of the sperm whale is *Physeter catodon* Linnaeus 1758.

In press: *Marine Mammal Science*.

Supported by: WHOI.

WHOI Contribution No. 6079.

AN OPTICAL TELEMETRY DEVICE TO IDENTIFY WHICH DOLPHIN PRODUCES A SOUND

Peter Tyack

A small telemetry device, called a vocalight, was designed for attachment to a dolphin's head using a suction cup. The vocalight lights up a variable number of light emitting diodes depending upon the loudness of sounds received at a hydrophone within the suction cup. If vocalights matched for sensitivity are put on each dolphin within a captive group, observers can identify which dolphin produces a vocalization. Use of vocalights indicates that source levels of whistles from captive bottlenosed dolphins, *Tursiops truncatus*, range from approximately 125 to 140 dB re 1 μ Pa at 1 m.

Published in: *Journal of the Acoustical Society of America*, 78(5), 1892-1895, 1985.

Supported by: WHOI Postdoctoral Scholar Award and NIH Postdoctoral Fellowship 5-F32-NS07206.

WHOI Contribution No. 5941.

WHISTLE REPERTOIRES OF TWO BOTTLENOSED DOLPHINS, *Tursiops truncatus*: MIMICRY OF SIGNATURE WHISTLES?

Peter Tyack

The whistle vocalizations of two bottlenosed dolphins, *Tursiops truncatus*, were recorded at the Sealand Aquarium in Brewster, Massachusetts. The identification of which dolphin within the group produced a vocalization was made possible by a telemetry device attached to the dolphin's head with a suction cup. Seventy-seven percent of the identified whistles (219 out of 284) fell into two primary categories, type 1 and type 2. The remaining 23% of whistles fell into five secondary categories. Of the primary whistles produced by one dolphin, 78% were of type 1 (22% type 2), while 69% of primary whistles from the other dolphin were of type 2 (31% type 1). The result that

each of the dolphins favored a different primary whistle supports the findings of Caldwell and Caldwell (1965), that each dolphin produces an individually distinctive whistle. But in the present study, both dolphins produced both primary whistle types. This may represent mimicry of signature whistles.

In press: Behavioral Ecology and Sociobiology.

Supported by: WHOI Postdoctoral Scholar Award and NIH Postdoctoral Fellowship 5-F32-NS07206.

WHOI Contribution No. 5929.

CHANGES OBSERVED IN THE REACTION OF WHALES TO HUMAN ACTIVITIES

William A. Watkins

A review of our marine mammal observations of more than 25 years indicated that each of the species commonly observed within 35 km of Cape Cod reacted differently to stimuli from human activities. Over the years of exposure to ships, for example, minke whales (Balaenoptera acutorostrata) have changed from frequent positive interest to a general lack of interest, finback whales (B. physalus) have changed from generally negative to uninterested reactions, right whales (Eubalaena glacialis) have apparently continued the same variety of responses with little change, and humpbacks (Megaptera novaeangliae) have dramatically changed from relative disinterest to often strongly positive reactions. These reactions appeared to result mostly from three types of stimuli: underwater sound was the primary cause of reaction, then light reflectivity, and tactile sensation. The reactions of the whales were related to their perception of the stimuli as interesting or disturbing, their perception of the movements of the sources of the stimuli relative to their own positions, and their perception of the occurrence of stimuli as expected or unexpected. The reactions were modified by the whales' previous experience and current activity: habituation occurred rapidly, attention to other stimuli or preoccupation with their own activities overcame their interest or wariness of stimuli, and inactivity seemed to allow whales to notice and react to stimuli that otherwise might have been ignored. The changes over time in the reactions of whales to stimuli from human activities were gradual and constantly varying with increased exposure to these activities and with their levels of habituation.

Supported by: ONR Contract N00014-82-0019, NR 083-004 and National Marine Fisheries Contract 50-EANF-5-00068.

WHOI Contribution No. 6072.

THE USE OF RADIO TAGS IN TRACKING LARGE WHALES -- A REVIEW OF PRESENT KNOWLEDGE

William A. Watkins

The objectives of radio tagging of whales are to provide unequivocal identification of individuals, positive tracking of their movements, and detailed observation of their behavior and activities. The rate of signal re-acquisition dictates the relative detail in the tracking data -- occasional monitoring provides only a few points on the track, while continuous tracking allows detailed observations of surfacing and movements. The advantages of radio tagging over other systems of monitoring whales are the reliability of the identifications and of the tracking data over relatively long distances and in spite of any intervening poor visibility or weather conditions. Radio tags used with a wide variety of whale species demonstrate that the tags do not affect the behavior of any of the whales, and tracking does not disrupt any whale activities.

Tracking of radio tag signals is positive and consistent, with interference minimized by shifting tag frequencies away from noisy bands and by restricting the receiver bandwidth. Signal reliability may be enhanced by higher power, by designs that reduce detuning effects of tag antenna angle and proximity with the water, and by wide receiving angles so that signals are not missed. Tracking is easiest with automatic direction-finding (ADF) receivers and lower frequencies which are not blocked by waves and ice irregularities but which bend over such obstructions. Surface and aerial tracking are both practical, with different results depending on tag frequency -- generally the lower the frequency, the longer the signal ranges, but the noisier the reception.

Two tagging systems have been well tested on a variety of species. The one developed by Bruce Mate uses relatively small, low-power, high-frequency (160 MHz) tags. The Mate tag is attached externally to the back of a whale at distances of 4 to 6 m by a cluster of curved tines explosively driven into the outer layers of blubber, and it has apparently remained attached for a year or more. Our (WHOI-OAR) tag is higher power and larger to

allow the use of frequencies as low as 30 MHz. The WHOI/OAR tag is fired from a shoulder gun at distances to 50 m, it is imbedded in the blubber with only the antenna protruding, and it is expected to remain in place for shorter periods of one to three months. Both tagging systems transmit only when the antenna is out of water, and both can provide battery power for up to one year with normal whale behavior. The higher power and lower frequency capabilities of the WHOI/OAR units have provided longer ranges for both aerial (300 km +) and surface (30 km +) work, and they have allowed convenient ADF tracking.

Satellite tracked tags for whales also are in development (Mate/Telonics). These are larger units attached to a whale by clusters of tines. They appear to remain attached for a period of weeks, and with the present system can be located every few days.

Published in: Proceedings of the 3rd Conference on the Biology of the Bowhead Whale, Balaena mysticetus. January 1985, Anchorage, AK.

Supported by: WHOI.

WHOI Contribution No. 6104.

CODAS SHARED BY CARIBBEAN SPERM WHALES

William A. Watkins, Karen Moore
and Peter Tyack

Coda signals produced by sperm whales in the southeast Caribbean included the stereotyped, patterned click sequences that seem to be unique to individual whales and that are apparently used as individual identifiers. In addition, at least two 5-click codas were produced by numerous whales within most groups that were encountered during all cruises (Nov. 1981, Nov. 1983, and March 1984) in the area west of Union Island to Guadeloupe. Each of these two click patterns occurred sometimes in exchanges between whales, and they were occasionally produced in overlapping sequences by up to two and three individuals at one time. These shared codas are similar to the apparent identity codas, but they are used by many individuals. The behavioral contexts associated with the shared codas (disassociation, agonism, vocal response) imply significance that is different for these shared codas.

Published in: Proceedings of the 6th Biennial Conference on the Biology of Marine Mammals. November 1985, Vancouver, BC.

Supported by: Kendall Foundation.

WHOI Contribution No. 6103.

MARINE POLLUTION

BIOLOGICAL EFFECTS OF PETROLEUM HYDROCARBONS ON MARINE ORGANISMS: INTEGRATION OF EXPERIMENTAL RESULTS AND PREDICTIONS OF IMPACTS

Judith M. Capuzzo

Biological effects of petroleum hydrocarbons on marine organisms are dependent on their persistence and bioavailability, the ability of the organisms to accumulate and metabolize various hydrocarbons, the fate of metabolized products, and the interference of hydrocarbons with normal metabolic processes that may alter an organism's chances for survival and reproduction in the environment. In considering the long-term effects of petroleum hydrocarbons in the environment, it is important to ascertain what biological effects may result in subtle ecological changes, changes in community structure and function, and possible impairment of fisheries resources. Although a wide range of stress indices have been proposed for monitoring pollutant impacts on marine organisms, no single index can provide the predictive capability to evaluate population or community changes. Understanding the relationship and integration of multiple stress indices should improve our capabilities of predicting long-term change at organismal and population levels before irreversible damage occurs at the community and ecosystem levels.

In press: Marine Environmental Research.

Supported by: NOAA Grant
NA84AA-D-00048.

WHOI Contribution No. 5934.

ECOLOGICAL AND HUMAN HEALTH CRITERIA FOR CROSS ECOSYSTEM COMPARISON OF WASTE DISPOSAL IMPACTS

Judith M. Capuzzo, John M. Teal
and Robert K. Bastian

The risk to human health, degree of ecosystem damage, recovery time necessary to restore a natural community, and the resiliency of a system to further damage

should be considered in any comparison of waste disposal options. Engineering considerations for waste disposal practices are quite distinct for land and sea disposal options, yet a common set of criteria, delineating how different ecosystems respond to perturbations and identifying by what pathways toxicants are transferred to man, can be developed. This paper addresses the formulation of such criteria and their applicability in understanding the relative sensitivity of different ecosystems to waste disposal impacts and the relative risks to man of various waste disposal options.

In press: "Scientific Basis for the Role of the Oceans as a Waste Disposal Option." D. Reidel Publishing Company, Dordrecht, Holland.

Supported by: Battelle Memorial Laboratories Contract 68-01-6986 under EPA Subcontract F-4190 (8834)-488.

WHOI Contribution No. 5925.

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

SYMBIOTIC ASSIMILATION OF CO₂ IN TWO HYDROTHERMAL VENT ANIMALS, THE MUSSEL Bathymodiolus thermophilus AND THE TUBE WORM Riftia pachyptila

Shimshon Belkin, Douglas C. Nelson and Holger W. Jannasch

In shipboard studies, major differences were found in the incorporation of CO₂ by the specific prokaryotic symbionts of two deep sea vent invertebrates. With fresh trophosome material from the pogonophoran tube worm Riftia pachyptila, the rate of CO₂ fixation was found to be optimal at approximately 22°C. Sulfide, but not thiosulfate, served as the electron donor. Thirty-five percent of the aerobic rate remained in deoxygenated samples presumably due to traces of hemoglobin-bound oxygen. Gill preparations from the mytilid mussel Bathymodiolus thermophilus, on the other hand, assimilated CO₂ with a maximum rate at 12° to 15°C. Thiosulfate, but not sulfide, served as the electron donor. In deoxygenated samples the activity was completely inhibited. These metabolic dissimilarities between the symbionts of the two hosts extend to DNA base ratios and cell sizes. Partial fractionation of

the mussel gill preparation yielded a prokaryotic or "bacterial" fraction that showed a CO₂ assimilation rate three-fold higher than that of the crude homogenate. This activity was not affected by the in situ hydrostatic pressure of 250 atm (100% barotolerance). The mussel gill symbiont represents the first sulfur-oxidizing vent prokaryote with psychrophilic growth characteristics. The natural distribution of R. pachyptila and B. thermophilus within the physicochemical regime of the immediate vent vicinity corresponds well with the metabolic differences of their symbionts.

Published in: Biological Bulletin, 170, 110-121, 1986.

Supported by: NSF Grant OCE83-08631.

WHOI Contribution No. 5969.

A NEW SULFUR-REDUCING, EXTREMELY THERMOPHILIC EUBACTERIUM FROM A SUBMARINE THERMAL VENT

Shimshon Belkin, Carl O. Wirsen and Holger W. Jannasch

A newly described bacterial isolate, designated Strain NS-E, differs from presently known extremely thermophilic bacteria in various characteristics. It is a strictly heterotrophic eubacterium of marine origin and has a temperature range for growth of 50-95°C with an optimum at 77°C and a pH of 7.5. Its DNA base composition is 41.3 mol % guanine + cytosine. It is obligately anaerobic, utilizes various sugars as well as yeast extract, and reduces elemental sulfur facultatively to hydrogen sulfide. In 24 hr cultures cell densities are up to four-fold higher in the presence than in the absence of elemental sulfur. Sulfide concentrations of 1.0 and 10.0 µM limit growth by 65 and 95 percent, respectively. Oxygen sensitivity is apparent only at or above that range of temperature at which growth occurs.

Supported by: NSF Grant OCE83-08631.

WHOI Contribution No. 6061.

LEBEN IN DER TIEFSEE AUF CHEMOSYNTHETISCHER BASIS

Holger W. Jannasch

Seawater circulation through the earth's crust at tectonic seafloor spreading centers leads to the transformation of

geothermal into geochemical energy which is then emitted from hydrothermal vents in the form of reduced inorganic compounds. Their chemoautotrophic oxidation results in the production of microbial biomass. This serves as the base of the food chain which generates specific deep sea hydrothermal vent communities involving a novel type of symbiosis between chemosynthetic bacteria and newly described marine invertebrates.

Published in: *Naturwissenschaften*,
72, 285-290, 1985.

Supported by: NSF Grant OCE83-08631.

WHOI Contribution No. 5887.

THE CHEMOSYNTHETIC SUPPORT OF LIFE
AND THE MICROBIAL DIVERSITY AT DEEP
SEA HYDROTHERMAL VENTS

Holger W. Jannasch

Circulation of seawater through the upper few kilometers of oceanic crust at tectonic spreading zones result in a transformation of geothermal into chemical energy. Reduced inorganic species are emitted from warm (< 25°C) and hot (< 400°C) vents on the deep sea floor at depths of 1600 to 3000 m and are used by chemolithotrophic bacteria as terrestrial sources of energy for the primary production of organic carbon from carbon dioxide. Thus, the rich and unique animal populations found in the immediate vicinity of the vents represent ecosystems that are largely or solely independent of solar energy. They subsist by means of a food chain that is based on various microbial processes. In addition to aerobic and anaerobic bacterial chemosynthesis, a new type of symbiosis between yet undescribed chemolithotrophic prokaryotes and certain invertebrates appears to account for the major part of the total primary production at the deep sea vent sites.

Published in: *Proceedings of the
Royal Society (London)*, B225,
277-297, 1985.

Supported by: NSF Grant OCE83-08631.

WHOI Contribution No. 5888.

A CYANOBACTERIUM CAPABLE
OF SWIMMING MOTILITY

John B. Waterbury, Joanne M. Willey,
Diana G. Franks, Frederica W. Valois
and Stanley W. Watson

A novel cyanobacterium capable of swimming motility was isolated in pure culture from several locations in the Atlantic Ocean. It is a small unicellular form, assignable to the genus *Synechococcus*, that is capable of swimming through liquids at speeds of 25 $\mu\text{m sec}^{-1}$. Light microscopy revealed that the motile cells display many features characteristic of bacterial flagellar motility. However, electron microscopy failed to reveal flagella and shearing did not arrest motility, indicating that this cyanobacterium may be propelled by a novel mechanism.

Published in: *Science*, 230, 74-76,
1985.

Supported by: NSF Grant OCE82-14889.

WHOI Contribution No. 5945.

Nitrospira marina GEN. NOV. SP.
NOV.: A CHEMOLITHOTROPHIC
NITRITE-OXIDIZING BACTERIUM

Stanley W. Watson, Eberhard Bock,
Frederica W. Valois, John B. Waterbury
and Ursula Schlosser

A new chemolithotrophic nitrite-oxidizing bacterium, for which the name *Nitrospira marina* is proposed, was isolated from the Gulf of Maine. *N. marina* is a Gram-negative curved rod which may form spirals with 1 to 12 turns. Cells have a unique periplasmic space and lack intracytoplasmic membranes and carboxysomes. *N. marina* is an obligate chemolithotroph, but best growth is obtained in a mixotrophic medium. *N. marina* may be one of the most prevalent, nitrite-oxidizing bacteria in some oceanic environments. Type strain is filled with American Type Culture Collection (ATCC 43039).

In press: *Archives of Microbiology*.

Supported by: NSF Grant BSR84-07924.

WHOI Contribution No. 6081.

RATES OF MICROBIAL TRANSFORMATIONS IN
DEEP SEA SEDIMENTS: FREE VEHICLE STUDIES

Carl O. Wirsen and Holger W. Jannasch

Radiotracer techniques for the study of natural microbial populations are intended to assess the in situ metabolic activity (mainly using tritiated nucleotides) or potential turnover rates of specific substrates under the given in situ conditions. The second approach was preferred in deep-sea sediment studies where steady state conditions are unlikely to occur because of the heterogeneous distribution of nutrients as a result of a patchy input by depositing particulates. Recent sediment trap studies have shown that particulate matter reaching the deep sea does contain simple organic compounds. Therefore, the present experiments dealt with the measurement of carbon incorporation and respiration of ^{14}C -labeled acetate, glucose, glutamate and trimethylamine in deep sea sediments. Free vehicles were used for the in situ injection and incubation of cores at depths of 2600 to 5330 m. The data were compared to those obtained from (1) parallel samples incubated at 1 atm and in situ temperature and (2) a shallow-water station (Buzzards Bay, 12 m). Rates measured in situ generally decrease with water depth as well as with depth in the upper 9 cm of top sediment. In most experiments, rates measured in the 1 atm controls were higher than those observed in situ. This fact supports the general notion that natural populations of deep sea sediment contain barotolerant and barophilic microorganisms in varying proportions.

In press: Marine Biology.

Supported by: NSF Grant OCE83-08631.

WHOI Contribution No. 5946.

ACTIVITIES OF SULFUR-OXIDIZING BACTERIA AT THE 21°N EAST PACIFIC RISE VENT SITE

Carl O. Wirsen, Jon H. Tuttle
and Holger W. Jannasch

The incorporation of inorganic and organic carbon into cell material as well as the activities of carboxylating enzymes (ribulose biphosphate carboxylase and phosphoenol pyruvate carboxylase) were measured in waters emitted from "warm" vents at the 21°N ocean spreading site (depth 2600 m) of the East Pacific Rise. Both obligately and facultatively chemoautotrophic bacteria were present and comprised a significant but variable portion of the total microbial population as indicated by comparisons of microscopic cell counts with liquid enrichments and colony counts on media containing reduced sulfur

compounds. The proportion of chemoautotrophic sulfur oxidizing bacteria maximally reached 79% of the total microbial population based on ribulose biphosphate carboxylase activity. Variability of chemoautotrophic activity occurred between vents at different locations, but was also observed in one individual vent. Maximum rates of CO_2 incorporation in warm vent water were similar to levels measured previously in the $\text{O}_2/\text{H}_2\text{S}$ interface of the Black Sea. In shipboard experiments, these rates were virtually unaffected by in situ pressures (ca. 260 atm). Rate measurements at various temperatures as well as the observed mesophilic characteristics of all isolates obtained suggest that the microbial chemoautotrophic activity decreases rapidly as freshly emitted vent water is diluted with cold ambient deep-sea water.

Supported by: NSF Grants OCE83-08631
and OCE84-16206.

WHOI Contribution No. 6071.

P L A N K T O N D Y N A M I C S

THE DINOFLAGELLATES

Donald M. Anderson

The dinoflagellates (Division Pyrrophyta, Class Dinophyceae) are one of the more important groups of phytoplankton in the ocean. Their adaptation to a wide variety of environments is evidenced by a tremendous diversity in form and nutrition and by an extensive fossil record dating back several hundred million years. As swimming cells, they can flourish under conditions that are unsuitable for many non-motile phytoplankton, a success due in part to unique behavior patterns. Some produce toxins that are dangerous to man and other components of the marine food chain; others are bioluminescent and emit light; some function as parasites or symbionts that rely on host organisms for part of their nutrition; many are photosynthetic, but an equal number obtain their carbon by ingesting other phytoplankton. It is thus no surprise that these organisms have been extensively studied, classified as plants by some workers and as animals by others. This chapter will describe the morphological, behavioral, physiological, and ecological characteristics of this group, emphasizing where possible the attributes that make dinoflagellates unique and important mem-

bers of the marine phytoplankton community.

Supported by: NSF Grants OCE83-15262 and OCE84-00292.

WHOI Contribution No. 6108.

DINOFLLAGELLATE CYST DYNAMICS IN COASTAL AND ESTUARINE WATERS

Donald M. Anderson and Bruce A. Keafer

Gonyaulax tamarensis cyst dynamics were studied in a shallow estuarine embayment and in deeper nearshore waters. In these two locations, the cysts accumulate in basins with other fine particulate materials, they are buried below the sediment surface such that the majority are found in anoxic sediments which can inhibit germination, their total abundance is very high, and their germination is restricted to surface sediments and therefore is small relative to the number of cells in a bloom. The major differences are in the timing and duration of germination. A tight temporal coupling between excystment and bloom initiation is apparent in the estuary where cysts germinate during a one month interval coinciding with the motile cell bloom. Germination begins at a lower temperature in the deeper coastal waters, precedes the motile cell bloom by several months and lasts eight months in total. The Gulf of Maine is thus seeded by the gradual germination of cysts over many months, providing multiple opportunities for bloom development. In the estuary, bloom success hinges on favorable conditions during a short period of active germination.

In press: Toxic Dinoflagellates, Proceedings of the 3rd International Conference. D. M. Anderson, A. White and D.G. Baden, eds. Elsevier Publishing Company.

Supported by: NOAA, Office of Sea Grant, Grant NA84AA-D-00033.

WHOI Contribution No. 5959.

SELECTIVE RETENTION OF TWO DINOFLLAGELLATES IN A WELL-MIXED ESTUARINE EMBAYMENT: THE IMPORTANCE OF DIEL VERTICAL MIGRATION AND SURFACE AVOIDANCE

Donald M. Anderson
and Keith D. Stolzenbach

The diel vertical migration patterns

of the dinoflagellates Gonyaulax tamarensis and Heterocapsa triquetra were monitored in an estuarine embayment subject to localized blooms of both species. A concurrent study of tidal flushing using a dye tracer demonstrated an efficient, density-driven mixing process that exchanged water within the embayment at a rate of approximately 0.5 day^{-1} . Loss rates of the whole pond populations of G. tamarensis and H. triquetra cells were smaller, ranging between 0.02 and 0.13 d^{-1} . The cells were thus able to maintain a non-mixed distribution even under weakly stratified conditions. This selective retention of the two species relative to water exchange was due to the differential advection of surface and bottom waters through the inlet channel and the general avoidance of high irradiance surface layers by the dinoflagellates. Both species migrated to irradiances equivalent to 30% of summer sunlight when nutrients were presumably non-limiting, resulting in subsurface aggregations 1-2 m deep. Under nutrient-limited conditions, G. tamarensis migration was restricted to irradiances at or below 10-15% summer sunlight. Planozygotes (a life cycle stage preceding cyst formation) migrated in a manner indistinguishable from the remainder of the nutrient-limited G. tamarensis population. The results help to explain the dominance of dinoflagellates in such embayments, the localization of their blooms, and the distribution of their resting cysts in the region.

Published in: Marine Ecology Progress Series, 25, 39-50, 1985.

Supported by: NOAA, Office of Sea Grant, Grants NA83AA-D-00049 and NA84AA-D-00033 and NOAA, Office of Oceanography and Marine Services, Grant NA81RA-D-00012.

WHOI Contribution No. 5885.

PRIMARY PRODUCTIVITY AND PELAGIC NITROGEN CYCLING

Patricia M. Glibert

The distinction between new (allochthonous) and regenerated (autochthonous) nitrogen is central not only to our understanding of phytoplankton nitrogenous nutrition and degree of dependence on one form versus another, but also to our understanding of nitrogen cycling and flux through the water column. A range of techniques, primarily ^{15}N tracer, ^{15}N isotope dilution, and ^{15}N natural abundance, are now available for assessing new

versus regenerated nitrogen utilization and production. These techniques differ in terms of the processes which they measure, in the time and space scales which they average, and in the perspective derived as to the relative importance of new nitrogen to phytoplankton production. In reconciling these discrepancies, the analytical problems and limitations associated with these approaches must be fully understood. Additionally, comparisons of data derived by these various techniques are made even more difficult by the fact that there are few data sets of phytoplankton nitrogen utilization and nitrogen flux with good spatial and temporal coverage. Most pressing is the need for a better understanding of the temporal coupling between phytoplankton utilization and NH_4^+ remineralization by a range of size classes of organisms, and the factors influencing this relationship. Also, regional and seasonal variations in the dependence of allochthonous versus autochthonous nitrogen need to be more fully resolved; in the coastal regime some newer techniques may be helpful in this regard.

In press: Nitrogen Cycling in Coastal, Marine Environments. T. Henry Blackburn and Jan Sorensen, eds. John Wiley, Publisher.

Supported by: NSF Grant OCE84-09465.

WHOI Contribution No. 5951.

ON PHYTOPLANKTON GROWTH RATES AND PARTICULATE C:N:P RATIOS IN CONTINUOUS CULTURES AND PELAGIC SURFACE WATERS

Joel C. Goldman

Large deviations in cellular C:N:P ratios from the Redfield ratio of 106:16:1 occurred only as a function of low relative growth rate $D:\mu(I_0)$ and not of low light intensity (I_0) in a series of continuous culture experiments involving nitrogen-limited growth of the chrysophyte *Pavlova lutheri* (Mono). In growing phytoplankton at low dilution rates and very low light intensities, it must be recognized that cell self-shading can lead to reductions in light intensity within the culture and concomitantly cause reductions in the absolute maximum growth rate $\mu(I_0)$ that applies to those conditions. Thus the relative growth rate $D:\mu(I_0)$ is really greater than if based on a value of $\mu(I_0)$ corresponding to the incident irradiation.

Additionally, because both light intensity and dilution rate are independent variables in continuous culture operation,

the light-limited continuous culture can not be used to simulate the natural environment where light intensity is still the independent variable but growth rate is the dependent variable. Thus, because light-limited phytoplankton in continuous culture can attain the Redfield chemical proportions at all combinations of light intensity and dilution rate, this does invalidate the hypothesis that attainment of Redfield proportions in nature implies that resident phytoplankton are growing at relative growth rates approaching 1 and are close to nutrient sufficiency. From recent oceanic studies, there is an abundance of data to support the concept that the chemical composition of oceanic phytoplankton typically is in the Redfield proportions.

Supported by: NSF Grant OCE83-08578.

WHOI Contribution No. 6083.

EXPERIMENTAL STUDIES ON AN OMNIVOROUS MICROFLAGELLATE: IMPLICATIONS FOR GRAZING AND NUTRIENT REGENERATION IN THE MARINE MICROBIAL FOOD CHAIN

Joel C. Goldman and David A. Caron

A phagotrophic marine microflagellate *Paraphysomonas imperforata* was found to graze on a wide assortment of phytoplankton species as well as bacteria; it also resorted to cannibalism when food was in short supply. Growth rates of the microflagellate were higher than those of the phytoplankton prey, although in some cases lower measured growth rates were found when there was aggregation of cells. This aggregation seemed to be bacterially mediated. The ratio of predator to prey cell size varied from about 2 for the phytoplankton prey to 7 for bacteria. Nitrogen regeneration by the microflagellate, primarily as NH_4^+ , never exceeded 50% of the nitrogen originally incorporated by the phytoplankton and bacterial prey. The role of bacteria in regenerating nutrients was found to be minimal relative to microflagellates. These results imply that both omnivory by small protozoa and a greater flexibility in the relationship between predator and prey sizes should be incorporated on the contemporary "microbial food loop" concept. In addition, to achieve 80-90% nutrient regeneration in pelagic surface waters, as is generally believed to occur, requires that the microbial food web be exceedingly complex with a hierarchy of, at least, several grazing steps. Alternatively, nutrient regeneration efficiencies in surface waters may be lower than envisioned.

Published in: Deep Sea Research, 32,
899-915, 1985.

Supported by: NSF Grant OCE83-08578.

WHOI Contribution No. 5896.

NUTRIENT CYCLING IN A MICROFLAGELLATE FOOD CHAIN: I. NITROGEN DYNAMICS

Joel C. Goldman, David A. Caron,
O. Ketil Anderson and Mark R. Dennett

In a series of grazing experiments, we found that the phagotrophic microflagellate *Paraphysomonas imperforata* (Lucas) (7 to 12 μm dia.) fed equally well on the diatom *Phaeodactylum tricornutum* and bacteria under batch conditions. Growth rates of the microflagellate were considerably higher than those of the phytoplankton prey. Regeneration of NH_4^+ was negligible in control cultures of phytoplankton alone, bacteria alone, or phytoplankton and bacteria. However, when the microflagellate was grazing on either phytoplankton or bacteria there was considerable regeneration of NH_4^+ . This result was a clear indication that only the microflagellate was responsible for the excretion. Rates of NH_4^+ excretion were highest during exponential growth of the microflagellate and slackened off considerably with onset of the stationary phase when growth of the prey was not nutrient-limited. Regeneration efficiencies, however, were lowest during exponential growth (15-30%), but increased to 50% if calculated on the basis of the entire experiment which included the stationary phase. Regeneration efficiencies during exponential growth decreased to 8% when the prey was grown under nitrogen-limitation. Nitrogen turnover rates per body weight are generally much higher in microflagellates than in macrozooplankton, but can be greatly influenced by many environmental factors including prey nutritional state.

Published in: Marine Ecology Progress
Series, 24, 231-242, 1985.

Supported by: NSF Grant OCE83-8578.

WHOI Contribution No. 5863.

NUTRIENT CYCLING IN A MICROFLAGELLATE FOOD CHAIN: II. POPULATION DYNAMICS AND CARBON CYCLING

David A. Caron, Joel C. Goldman,
O. Ketil Anderson and Mark R. Dennett

Carbon cycling in a 3-member food web containing a diatom (*Phaeodactylum tricornutum*), bacteria, and a herbivorous/bacterivorous microflagellate (*Paraphysomonas imperforata*) was examined. Ingestion of prey by the microflagellate was the primary mechanism for remineralization of particulate organic material. Approximately 65% of the particulate organic carbon (POC) initially present was lost over the course of the 8-d experiments in cultures containing microflagellates. No significant increase in remineralization was observed when bacteria were present. Bacteria were responsible for the uptake of dissolved organic carbon (DOC), but their overall contribution to carbon cycling was small relative to that of the microflagellate. Microflagellates incorporated diatom and bacterial biomass with equal efficiency (44%) during exponential growth. Only 10% of the POC ingested by microflagellates was released as DOC while 10% was released as egested POC. The relatively high weight-specific respiration rate of the microflagellates

$$(X = 2.67 \times 10^{-5} \text{ n10}_2 \times \mu\text{m}^{-3} \text{ h}^{-1})$$

coupled with their relatively small release of DOC indicates that herbivory by heterotrophic microflagellates may be a major mechanism for the regeneration of nutrients from living phytoplankton which circumvents bacterial decomposition.

Published in: Marine Ecology Progress
Series, 24, 243-254, 1985.

Supported by: NSF Grant OCE83-08578.

WHOI Contribution No. 5864.

NUTRIENT CYCLING IN A MICROFLAGELLATE FOOD CHAIN. III. PHOSPHORUS DYNAMICS

O. Ketil Anderson, Joel C. Goldman,
David A. Caron and Mark R. Dennett

As part of a series of grazing experiments in batch cultures, we found that the phagotrophic microflagellate *Paraphysomonas imperforata*, while grazing on the diatom *Phaeodactylum tricornutum* or bacteria, was responsible for the bulk of phosphorus regeneration. Regeneration of soluble reactive phosphorus (SRP) and dissolved organic phosphorus (DOP) was negligible in control cultures of the diatom alone, bacteria alone, or the two microbes together. When the microflagellate grazed on prey organisms that had been pre-cultured with excess nutrients or under nitrogen limitation there was considerable regeneration of total dissolved phosphorus

(TDP = SRP + DOC). Rates of TDP regeneration were greatest during exponential growth of the microflagellate and then decreased through the transition and stationary phases. Overall, up to 70% of phosphorus initially incorporated into prey biomass was regenerated through the stationary phase. Total excretion of DOP was about 15-20% of TDP, although DOP excretion made up a larger fraction of total phosphorus excretion for short periods during the exponential phase of growth. When the prey were phosphorus-limited, virtually no TDP was excreted throughout the entire growth cycle of the microflagellate. Our results indicate that protozoa have higher weight specific rates of phosphorus excretion than metazoa. Although metabolic activity is not a sole indicator of the role protozoa play in the nutrient regeneration process, our results, together with those from size-fractionation studies on nutrient regeneration, point toward a major role for protozoa in pelagic waters where they constitute a large fraction of the zooplankton biomass.

Supported by: NSF Grant OCE83-08578;
Postdoctoral Fellowship from the
Norwegian Research Council.

WHOI Contribution No. 6060.

DARK CO₂ UPTAKE BY THE DIATOM *Chaetoceros simplex* IN RESPONSE TO NITROGEN PULSING

Joel C. Goldman and Mark R. Dennett

In a continuing investigation of dark CO₂ uptake by nitrogen-limited cultures of the marine diatom *Chaetoceros simplex* (Bbsm), we expanded on several of our earlier conclusions regarding the potential application of this physiological response for measuring the degree and type of nitrogen limitation in phytoplankton populations. First, the duration over which the maximum enhancement of dark ¹⁴C₂ uptake was sustained after NH₄⁺ enrichment was a function both of the concentration of added NH₄⁺ and the standing crop of phytoplankton nitrogen -- in effect, the total N demand. Second, pulsing with NH₄⁺ for a given degree of N-limitation always produced the same level of enhanced dark CO₂ uptake regardless of whether the cultures were preconditioned with oxidized or reduced nitrogen. In contrast, urea pulsing led to reduced dark CO₂ uptake, but the effect was most pronounced in cells grown on NO₃⁻. And third, the assay could be used to distinguish readily between no, moderate, and severe N limita-

tion. The degree of severe N limitation was quantitatively correlated with the degree of enhanced dark CO₂ uptake, but this relationship was not so clear in the region of moderate N limitation. The main advantage of the assay is that it is a relatively simple and effective alternative to more complicated techniques for gauging the degree and form of N limitation in phytoplankton. Further evaluation will be required, both in the laboratory and field, before the assay can be calibrated for quantitative use.

In press: Marine Biology.

Supported by: NSF Grants OCE82-19578
and OCE83-08578.

WHOI Contribution No. 5982.

THECATE HETEROTROPHIC DINOFLAGELLATES FEEDING BEHAVIOR AND MECHANISMS

Dean M. Jacobson and Donald M. Anderson

The feeding of 17 species of thecate heterotrophic dinoflagellates from 3 genera (*Protoperidinium*, *Oblea*, *Zygabikodinium*) can all be described within one general framework. These species engulf diatoms and other prey with a pseudopod (herein termed a "pallium") which originates at the flagellar pore in the sulcus. The pallium is a highly plastic, membranous organ which easily stretches to accommodate spines and other protrusions, and has been observed to enclose as many as 58 diatom cells in a chain. The contents of the phytoplankton prey are liquified and transported through the pallium typically within 7 to 30 minutes of capture (although feeding may last two hrs.), leaving an intact but empty cell wall or frustule. Thus far, with few exceptions, *Protoperidinium* species have been observed feeding only on diatoms, whereas two diplopsaloid species feed on dinoflagellates and prasinophytes as well. In four species from the three genera studied, a capture filament has been observed that connects the food to the dinoflagellate prior to extension of the pallium, sometimes allowing the cell to pull the food while swimming. A distinctive precapture swimming behavior is also described for six species, suggesting that the dinoflagellates are selective grazers.

Supported by: NSF Doctoral Fellowship
by the Education Program; Coastal
Research Center at WHOI; and NSF
Grant OCE84-00292.

WHOI Contribution No. 6044.

DIEL PERIODICITY IN THE PHOTOSYNTHETIC
CAPACITY OF COASTAL AND OFFSHORE
PHYTOPLANKTON ASSEMBLAGES

Todd M. Kana, Jennifer L. Watts
and Patricia M. Glibert

Diel changes in the photosynthetic-irradiance response of phytoplankton were measured in coastal, neritic, and oceanic waters. In each site, maximum daily light-saturated photosynthesis rates were 2-3 times higher than rates recorded either at dawn or dusk. Time of day that maximum occurred varied with site and depth. Diel measurements in the coastal water indicated that minimum photosynthetic capacity occurred in the middle of the night, that up to one half of the total diel change occurred at night, and that times of most rapid change occurred around dawn and dusk. Independent measurements of nitrogen nutritional status on the neritic and oceanic assemblages indicated that there was no nitrogen limitation for phytoplankton growth.

Published in: Marine Ecological
Progress Series, 25, 131-139, 1985.

Supported by: WHOI Mellon Study
Award and WHOI Summer Student
Fellowship to Jennifer Watts.

WHOI Contribution No. 5873.

ENDOGENOUS CONTROL OF SPAWNING
IN A MARINE COPEPOD

Nancy H. Marcus

Daily pattern of egg release was studied in the marine calanoid copepod, Labidocera aestiva (Wheeler) under cycling light-dark (12L-12D, 12D-12L) conditions, and constant light (24L) or darkness (24D). Under cycling conditions, maximum egg release occurred during the dark phase. Rhythmic spawning was also evident under 24D, but not under 24L. The results suggest that the pattern of nocturnal egg release is regulated by an endogenous rhythm entrained by light.

Published by: Journal of Experimental
Marine Biology and Ecology, 91,
263-269, 1985.

Supported by: NSF Grant OCE82-14882
and WHOI Mellon Study Award.

WHOI Contribution No. 5884.

POPULATION DYNAMICS OF MARINE COPEPODS:
THE IMPORTANCE OF PHOTOPERIODISM

Nancy H. Marcus

Biological oceanographers have traditionally emphasized food and temperature as the most important factors governing the population dynamics of marine copepods. This paper addresses the importance of light and light-dark periods as stimuli for the induction of specific biological processes and activities. Attention is focused on photoperiodic control of dormancy and vertical migration and the rhythmic expression of daily functions, such as the timing of feeding and egg-laying. Emphasis is placed on relating the genetic basis of photoperiodic determined responses and activity rhythms to the population dynamics, ecology, and evolution of marine copepods and the maintenance of diverse zooplankton communities.

In press: The American Zoologist.

Supported by: NSF Grant OCE82-14882
and WHOI Mellon Study Award.

WHOI Contribution No. 5886.

RESPONSE OF THE BIOLUMINESCENT
DINOFLLAGELLATE Gonyaulax polyedra TO
PARAMETERS OF FLUID MOTION

G. T. Reynolds, A. J. Walton,
D. M. Nosenchuck and D. M. Anderson

We have determined the bioluminescence response of Gonyaulax polyedra to various mechanical stimuli. By means of image intensification techniques, observations were made of the response in dilute suspensions of the dinoflagellate to various parameters of fluid flow, and the flow patterns set up by the passage to various objects moving with velocities corresponding to a wide range of Reynolds numbers. Records were obtained on video tape for dynamic analysis, as well as on film for integrated effects. We are able to conclude that response depends on rates of change of parameters such as shear, acceleration and pressure, and does not occur in fields of constant values of these quantities. The dynamic studies also indicate that these microorganisms can serve as a useful means of studying fluid flow patterns.

Supported by: DoE Contract EY-76-S-
02-3120; ONR Contract N00014-83-
0234; and NSF Grant OCE82-08739.

WHOI Contribution No. 5866.

SELECTIVE FEEDING BY Balanion SP.
(CILIATA, BALANIONIDAE) ON PHYTOPLANKTON
THAT BEST SUPPORT ITS GROWTH

Diane K. Stoecker, Terry L. Cucci and
Clarice M. Yentsch

The planktonic ciliate Balanion sp. feeds preferentially on certain dinoflagellates when confronted with mixtures of microalgae. The preferred prey are species which support its fastest growth (about 3 div./d at 15° C). At high food densities, Balanion can grow as rapidly in algal mixtures which contain its preferred prey as its corresponding monocultures. Balanion is found year-round in estuaries in which dinoflagellates are common but are only occasionally the dominant phytoplankters. Preferential ingestion of suitable dinoflagellate prey may thus increase the growth rate of this ciliate in situ.

In press: Journal of Experimental
Marine Biology & Ecology.

Supported by: NSF Grants OCE83-15370
and OCE81-21331.

WHOI Contribution No. 5872.

EFFECTS OF COPPER AND ZINC ON TWO
PLANKTONIC CILIATES

D. K. Stoecker, W. G. Sunda
and L. H. Davis

The interactive effects of copper and zinc on two estuarine planktonic ciliates, Favella sp. and Balanion sp., were determined in seawater media in which the free metal ion activities were controlled by nitrilotriacetic acid (NTA) trace metal ion buffer systems. Cupric ion activities of 10^{-10} M caused abnormal motility in both ciliates in short-term (5 h) tests, and cupric ion activities as low as $10^{-12.8}$ M decreased the growth rates of both species in longer-term experiments. In the short-term tests, zinc ion activity by itself did not affect the motility of the ciliates, but there was a synergistic interaction between copper and zinc. In the longer term experiments, the growth of Favella sp. was optimum at the lowest cupric ion activity (10^{-13} M) and the two lowest zinc ion activities (10^{-12} and 10^{-11} M), and copper toxicity or zinc toxicity occurred at activities above these values. By contrast, optimum growth rate of Balanion sp. occurred at the highest zinc ion activity (10^{-10} M) and lowest cupric ion activities (10^{-13} to 10^{-12} M). Zinc nutritional limitation

occurred at zinc ion activities $\leq 10^{-11}$ M. In Balanion sp. there was a strong antagonistic interaction between copper and zinc in which increases in cupric ion activity greatly accentuated the zinc limitation.

In press: Marine Biology.

Supported by: NOAA, Office of Sea
Grant, Grants NA81RA-D0014 and
NA80AA-D-00077.

WHOI Contribution No. 5871.

DISCRIMINATION BETWEEN PIGMENT TYPES
OF MARINE Synechococcus SPP. BY
SCANNING SPECTROSCOPY, EPIFLUORESCENCE
MICROSCOPY, AND FLOW CYTOMETRY

A. Michelle Wood, P. K. Horan,
K. Muirhead, D. A. Phinney, C. M. Yentsch
and J. B. Waterbury

The in vivo spectral properties of nine clonal isolates of marine Synechococcus spp. were compared in order to identify characteristics which were associated with intact cells from each of three major pigment groups. On the basis of in vivo absorption and fluorescence excitation and emission spectra, distinctive differences were found between phycoerythrin (PE)-lacking clones, clones containing a PE composed of phycoerythrobilin and phycourobilin chromophores, and clones containing a PE composed of only phycoerythrobilin chromophores. These differences can be detected analytically by both epifluorescence microscopy and flow cytometry and were observed in clones grown in different environments and at different stages of growth and/or nutrient limitation. Thus, these spectral characters reflect intrinsic differences between the three pigment groups and can be used to identify genetically distinct subpopulations of marine Synechococcus spp. in natural waters.

Published in: Limnology and
Oceanography, 30, 1303-1315, 1985.

Supported by: NIH Grant GM 26786; an
American Association of University
Women Postdoctoral Fellowship; a
Grant from Hinds Fund of the
University of Chicago; and NSF
Grants OCE81-21331 and OCE82-14889.

WHOI Contribution No. 6056.

POPULATION ECOLOGY

THE DEMOGRAPHIC AND EVOLUTIONARY CONSEQUENCES OF PLANKTONIC DEVELOPMENT

Hal Caswell

Over half of all marine invertebrate species have incorporated a planktonic larval stage into an otherwise benthic life cycle (Thorson 1950). The biogeographic implications of this life history pattern are profound (e.g. Scheltema 1978, Jablonski and Lutz 1983). Species with long planktonic larval stages tend to have greater geographical ranges and longer geological durations than those with restricted larval duration (see, e.g., Scheltema 1978 and Jablonski 1982 for data on gastropods). The relation of dispersal and gene flow also has important implications for patterns of local adaptation and speciation (Scheltema 1978). Hansen (1983), for example, finds that tropical neogastropods with non-planktotrophic development have exhibited greater speciation rates than those with planktotrophic development, presumably because the greater dispersal abilities of the latter make geographical isolation more difficult.

Supported by: NSF Grant BSR82-14583.

WHOI Contribution No. 6091.

TWO-SEX MODELS FOR STRUCTURED POPULATIONS: DYNAMICS AND STABILITY OF THE SEX RATIO

Hal Caswell

Most demographic models consider only one sex, usually females. The widespread occurrence of sexual dimorphism in life history traits and of skewed and fluctuating sex ratios suggest that two-sex demographic models may often be more appropriate. Reproduction in such models is described by a frequency dependent non-linear function of the relative abundance of males and females: the birth function or, in human demography, the marriage function. We incorporate three classes of birth functions into discrete time population projection matrices and examine the resultant population dynamics. For a wide variety of birth functions, models without inter-stage mate competition converge to a locally stable adult sex ratio. Formulae for the stable population structure, stable sex ratio and the reproductive value at equilibrium are derived. When individuals of different stages compete for mates,

the equilibrium population structure may become unstable. A sequence of bifurcations then occurs, leading to periodic oscillations, quasi-periodic fluctuations and chaos as the intensity of competition increases. Finally, when fecundity is a sigmoid function of the relative abundance of the other sex, perturbations of the sex ratio may lead to extinction.

Supported by: NSF Grant BSR82-14583;
NOAA, Office of Sea Grant, Grant
NA80AA-D-00077; and WHOI Summer
Student Fellowship.

WHOI Contribution No. 5933.

ELASTICITY AS A MEASURE OF THE RELATIVE CONTRIBUTION TO POPULATION GROWTH RATE IN MATRIX MODELS

Hans de Kroon, Anton Plaisier,
Jan van Groenenendael and Hal Caswell

Caswell's (1978) growth rate sensitivity measure is extended to an index ('elasticity') that quantifies the degree in which population growth is determined by alternative life history transitions. Sensitivities predict the impact of theoretical alterations in parameters on population growth rate. Elasticity analysis provides a tool for comparing these potential shifts with realized solutions in the field. Applied in combination with theoretical models, this index can facilitate a discussion of life history optimality in relation to the environmental processes that work on an actual population.

Supported by: NSF Grant BSR82-14583.

WHOI Contribution No. 6105.

DEMOGRAPHIC IMPORTANCE OF ECOLOGICAL INTERACTIONS: HOW MUCH DO STATISTICS TELL US?

James R. Weinberg, Hal Caswell
and Robert B. Whitlatch

Investigators generally accept the objective procedure of statistical null-hypothesis testing to determine which ecological interactions (e.g., competition, predation, mutualism) exist. Proof of existence, however, does not necessarily imply that an interaction controls a species' population size or distribution. Some statistically significant interactions may have little or no effect on population dynamics because they are weak and other factors dominate or because they affect individuals in the population with

low reproductive value. Nonetheless, many articles (see recent reviews in Peterson 1979; Jackson 1983; and Woodin 1983) contain subjective assessments of the degree to which ecological interactions control the distribution and abundance of species.

This paper presents an example of how one can quantify the importance of ecological interactions after their existence has been documented statistically via field and/or laboratory experiments. The analysis determines how much each interaction influences population growth rate (λe^r) and how sensitive λ is to perturbations of different stages of the life cycle. The approach uses λ as a summary statistic which incorporates the effects of the environment on age-specific birth and death rates of individuals (Andrewartha and Birch 1954).

Supported by: NSF Grants OCE80-18447
and BSR82-14583 and Doctoral
Dissertation Fellowships.

WHOI Contribution No. 6037.

Z O O P L A N K T O N

EFFECTS OF STARVATION ON MOULT CYCLE AND HEPATOPANCREAS OF STAGE I LOBSTER (Homarus americanus) LARVAE

K. Anger, V. Storch, V. Anger
and J. M. Capuzzo

Effects of feeding and starvation on the moult cycle and on the ultrastructure of hepatopancreas cells were studied in Stage I lobster larvae (Homarus americanus Milne Edwards). The relative significance of yolk and first food was quite different in larvae originating from two females. This difference was evident also in the amounts of stored lipid in the R-cells of the larval hepatopancreas. Most larvae from one hatch were, in principle, able to develop exclusively with yolk reserves (without food) to the second instar. The larvae from the second hatch showed lecithotrophic development only to the transition between late intermoult and early premoult (Stages C/D₀ of Drach's moult cycle) of the first larval instar. When initial starvation in this group lasted for three days or more, the point of no return (PNR) was exceeded. After the PNR, consumption of food was still possible, but development ceased in the transition C/D₀ or in late premoult (D₃₋₄). It is suggested that these stages of the moult cycle are critical points where

cessation of development and increased mortality are particularly likely in early larval lobsters under nutritional stress. Examination of hepatopancreas R-cells suggested that the PNR is caused by an irreversible loss of the ability to restore lipid reserves depleted during initial starvation. Initial periods of starvation ending before the PNR prolonged mainly Stage D₀ of the same instar (I). During this delay, structural changes in the R-cells caused by the preceding period of starvation were reversed: reduced lipid inclusions, swollen mitochondria, increased number of residual bodies indicating autolysis, and a reduction of the microvillous processes. Continually starved larvae which showed lecithotrophic development throughout the first instar and were then re-fed after moulting successfully, had a prolonged intermoult (Stage C) period in the second instar. This shows that, despite occasional lecithotrophy, food is an important factor in early larval development of the lobster.

Published in: Helgolander Meeres-
unters, 39, 107-116, 1985.

Supported by: WHOI Coastal Research
Center.

WHOI Contribution No. 6122.

THE STORAGE AND UTILIZATION OF BIOGENIC PARTICULATE MATTER IN DEEP MIXED LAYERS: OBSERVATIONS IN A WARM-CORE RING

J. K. B. Bishop, M. Conte, P. H. Wiebe
and M. R. Roman

Studies of particulate matter chemistry, depth specific particle gradients, particle size distribution, zooplankton biomass, and zooplankton grazing rates were made in the isolated waters of warm-core ring (WCR) 82B to investigate the response of these quantities to changes in water column primary productivity and vertical mixing between the time of ring formation in February 1982 and June 1982. Between February and April, the depth of the mixed layer of WCR 82B progressively increased to 400 m. In early May, surface waters showed the first evidence of stratification. By June, stratification extended to a depth of 40 m leaving an isolated thermocline between 40 and 400 m.

Evidence is presented to show that between the time of ring formation and the time of stratification in early May, particulate organic carbon, phosphate, calcium carbonate, and silica accumulated in thermocline waters due to the fact that mixing with deeper waters was the dominant

sink (70%) for biogenic particles produced in the euphotic zone. In the case of organic carbon, it was estimated that 2400 mmol C m^{-2} were mixed below the euphotic zone into the thermocline between February and April. The net increase in the particulate carbon loading of the thermocline over the same time interval was only 290 mmol C m^{-2} with the remaining organic matter being removed by zooplankton resident in the thermocline. The high supply rate of phytoplankton food to the waters below the euphotic zone by convective processes explained the nearly uniform distribution of zooplankton biomass over the upper 400 m in March and April.

In late April, zooplankton grazing and convective mixing equally contributed to the removal of organic carbon produced in the euphotic zone. After stratification of surface waters in early May there must have been a strong phytoplankton bloom (peaking in mid May) accompanied by a large increase in biogenic particulate matter in the euphotic zone because phytoplankton growth rates exceeded removal rates by a factor of two. Since stratification also ended the supply of phytoplankton food to the thermocline and since the zooplankton in the thermocline had a substantial grazing demand, it was estimated that it took less than one week for zooplankton to utilize all available food in 50-400 m depth interval. Following the removal of most organic matter from the thermocline, the zooplankton community shoaled to a restricted layer in close proximity to the euphotic zone. This response of zooplankton to a reduced food supply in the thermocline and to continued high rates of primary production in the surface waters explained the 20-fold enrichment of zooplankton biomass in the upper 50 m relative to deeper waters and also the large concentration gradients of particulate matter in the upper 100 m observed in June.

It is speculated that the coupling of primary production, mixing and zooplankton grazing observed in WCR 82B is typical of warm-core rings where deep mixed layers are progressively formed in winter months after which time stratification is established over a period of several days. It is also suggested that similar processes may occur in high-latitude temperate oceans where a similar pattern of mixed layer deepening and stratification is found.

In press: Deep Sea Research.

Supported by: NSF Grants OCE80-17468, OCE85-13420 and OCE81-17362.

WHOI Contribution No. 6067.

SMALL-SCALE, SHORT-TERM GENETIC HETEROGENEITY IN POPULATIONS OF THE EUPHAUSIIDS, *Euphausia krohnii* AND *Nematocelis megalops* FROM THE WESTERN NORTH ATLANTIC SLOPE WATER

Ann Bucklin and Peter Wiebe

Six collections of the euphausiids *Euphausia krohnii* and *Nematocelis megalops* were made in the western North Atlantic Slope Water between 37° to 39°N latitude and 65° to 74°W longitude during the period October 1981 and October 1982 with an additional collection in August 1984. Individuals were assayed by starch-gel electrophoresis for allelic variants of enzymes (allozymes), which may provide evidence of genetic isolation among conspecific populations. Electrophoretic phenotypes were determined for 8 loci encoding 5 enzymes. Both species were highly genetically variable (for *E. krohnii*, polymorphism, $P = 1.0$ and $H = 0.32$). The two species were genetically distinguishable by allozyme frequencies at the 8 loci (G test of heterogeneity, $G_{H(29)} = 714.6$, $P < 0.001$) and by a measure of genetic distance ($D = 0.29$). For each species, there was significant among-sample heterogeneity of allele frequencies ($G_{H(132)} = 791.5$ for *E. krohnii*, and $G_{H(125)} = 563.8$ for *N. megalops*, $P < 0.001$ for both). Genetic distances among samples of each species were typical of distances between geographically distinct conspecific populations (mean D between successive samples of *E. krohnii* = 0.12; between *N. megalops* samples, $D = 0.07$). Frequencies of the most common allele at each locus were not significantly correlated across samples (corrected $R_{(4)} = 0.314$ for *E. krohnii* and $R_{(1)} = 0.981$ for *N. megalops*, $P > 0.005$ for both). The apparent randomness of genetic heterogeneity among samples most probably results from genetically significant spatial and/or temporal patchiness in euphausiid populations. Heterogeneity among samples may also be a consequence of sampling error with small sample sizes and/or of seasonal changes in a population. Evidence of small-scale, short-term heterogeneity of allozyme frequencies in zooplankton populations suggests that allozymes may provide sensitive indicators of the biological significance of patchiness. Allozymes may indicate whether patches are reproductively isolated, genetically differentiated populations, or ephemeral aggregations in a genetically homogeneous population. Allozymic analysis of repeated collections in persistent, isolated water masses is required to determine the significance of short-term, small-scale genetic heterogeneity in zooplankton populations.

Supported by: NSF Grant OCE80-17248.

WHOI Contribution No. 5928.

A PARASITIC ASSOCIATION BETWEEN A
PYCNOGONID AND A SCYPHOMEDUSA IN MIDWATER

C. Allan Child and G. R. Harbison

Using a submersible, a specimen of the mesopelagic scyphomedusa, Periphylla periphylla (Peron and Lesueur 1809), was collected in midwater with an adult and two juvenile specimens of the pycnogonid, Pal-lenopsis (Bathypallenopsis) scoparia Fage 1956, attached to its subumbrellar surface. Evidence that the pycnogonids were feeding on the tentacles and other tissues of the jellyfish is given as well as suggestions as to the origin and maintenance of this relationship.

In press: Journal of Marine
Biological Association of the
United Kingdom.

Supported by: NSF Grant OCE84-00243.

WHOI Contribution No. 5892.

RESPIRATION AND EXCRETION
BY OCEANIC SALPS

Catherine M. Cetta, Laurence P. Madin
and Patricia Kremer

Rates of oxygen consumption and ammonium nitrogen excretion were measured on the solitary and/or aggregate generations of 10 species of oceanic salps collected by divers. Salps which had been held prior to incubation exhibited somewhat lower respiration and excretion rates and O:N ratios. Respiration rate showed a better relationship to length than to weight, suggesting that metabolic activity is connected mainly with swimming. Ammonium was the major excretory product in most species, but in some cases there was excretion of other nitrogenous compounds. Rates of metabolic demand (turnover) ranged from 9.7 to 99% body carbon d^{-1} and 6.4 to 55.6% body nitrogen d^{-1} . Species that were visibly more active had higher metabolic rates and calculated food requirements than did less active species.

Supported by: NSF Grant OCE83-15297.

WHOI Contribution No. 5988.

PRESERVATION ARTIFACTS AND THEIR EFFECTS
ON THE STUDY OF EUTHECOSOMATOUS
PTEROPOD MOLLUSCS

Ronald Gilmer

Inaccurate anatomical observations based on preserved specimens of euthecosomatous pteropod molluscs are shown to result from artifacts of preservation. All "aberrant" forms previously described in the literature (including the "minute" and "skinny" stages) can be induced in the laboratory by the addition of preservatives to normal living animals. That these aberrant forms have never been observed in nature further supports the contention that they are preservation artifacts.

In press: The Veliger.

Supported by: NSF Grant OCE82-09341.

WHOI Contribution No 5944.

FIELD BEHAVIOR OF PTEROPOD MOLLUSCS:
FEEDING METHODS IN THE FAMILIES
CAVOLINIIDAE AND PERACILIDIIDAE
(GASTROPODA, THECOSOMATA)

Ronald W. Gilmer and G. Richard Harbison

We studied the feeding behavior in situ of twelve species belonging to eight genera of thecosomatous pteropods, six in the family Cavoliniidae and one in the family Peracilidiidae. All cavoliniids feed with a large spherical mucous web but Peraclis reticulata uses a funnel-shaped mucous sheet, resembling that of other pseudothecosomes. Although the feeding mechanisms are similar in all the animals we examined closely, we have found great differences in the size and morphology of the external part of the mantle. In species of Cavolinia and Diacria, the external mantle attains its greatest complexity and appears to be used for the sorting or rejection of food and for flotation, since they appear to be neutrally buoyant. Species of the other four cavoliniid genera we studied have greatly reduced external mantles and sink slowly when feeding. Peraclis reticulata also has an extensive external mantle, completely covering the shell, and also appears to be neutrally buoyant. We conclude that feeding with a large mucous web explains the presence of fragments of large, fast moving prey in the stomach contents of many thecosomes. Presently, it is unknown whether thecosomes should be regarded as carnivorous trappers of prey or as suspension feeders. The use of an external mucous web

for feeding is probably common to all thecosome pteropods and is the fundamental adaptation that enables them to live holoplanktonically.

In press: Marine Biology.

Supported by: NSF Grant OCE82-09341.

WHOI Contribution No. 5857.

THE RESPONSE OF THE SALP, Pegea confoederata, TOO HIGH LEVELS OF PARTICULATE MATERIAL: TOO MUCH IS JUST AS BAD AS TOO LITTLE

G. R. Harbison, V. L. McAlister
and R. W. Gilmer

When the pelagic tunicate Pegea confoederata is presented with concentrations of particulate material equivalent to levels found in neritic areas, its feeding mechanism is disrupted. A bolus is formed that blocks the esophagus, dramatically decreasing the amount of material that enters the stomach. This bolus never occurs at particle concentrations lower than 0.5 ppm and always forms at particle concentrations above 5.0 ppm. For oceanic waters, 0.5 ppm lies in the upper range of values, so that it appears that P. confoederata is adapted for feeding on average concentrations of particulate material in the open sea. These results are in contrast to those with most of the calanoid copepods that have been studied. Since P. confoederata feeds on the oceanic average, it can be more evenly distributed throughout the great oceanic central waters masses, thereby decreasing the likelihood of its discovery by predators.

In press: Limnology and Oceanography.

Supported by: NSF Grants OCE75-21715, OCE77-22511 and OCE82-09341.

WHOI Contribution No. 5958.

SWARMING BEHAVIOR OF THE HYPERIID AMPHIPOD Anchylomera blossevilli

Phillip S. Lobel and John E. Randall

Swarms of the hyperiid amphipod Anchylomera blossevilli were observed underwater on 10 August 1982 off the Kona coast of Hawaii. The amphipod swarms exhibited unique behavior that included the formation of tornado-shaped swirls which formed at the surface and from which tightly massed batches of individuals drifted to deeper

depths. The swarms were monospecific with a sex ratio of 0.42 male:female; 19% of the females were bearing eggs. The physical, chemical, or biological basis for this swarming was not ascertained.

In press: Journal of Plankton Research.

Supported by: NSF Grant OCE80-09554.

WHOI Contribution No. 6062.

PRIMARY PRODUCTION AND GRAZING IN THE PLANKTON OF THE PANAMA BIGHT

John Marra, Peter H. Wiebe
and James K. B. Bishop

Measurements of chlorophyll *a*, phaeopigments, primary production, and zooplankton were made during the deployment cruise of the Sediment Trap Intercomparison Experiment (STIE) to the Panama Bight (5°20'N, 81°55'W) in August 1979. Integral chlorophyll *a* levels over the euphotic zone averaged 20.3 mg m⁻² and were not significantly different from day to day. Daily rates of primary production varied widely (200-700 mg C m⁻² day⁻¹). Phaeopigment levels were high and, on a molar basis, roughly equivalent to the amount of chlorophyll *a* in the euphotic zone. Zooplankton were most abundant in the top 100 m; dominant groups were copepods, ostracods, and chaetognaths. Estimates of macro- and microzooplankton grazing suggest that primary production and consumption were in balance on a time scale of one to a few days, and that microzooplankton were responsible for the bulk of the grazing impact.

Supported by: ONR Contracts N00014-75-C-0210 and N00014-80-C-098.

WHOI Contribution No. 6024.

NEW DEVELOPMENTS IN THE MOCNESS: AN APPARATUS FOR SAMPLING ZOOPLANKTON AND MICRONEKTON

Peter H. Wiebe, Alfred W. Morton,
Albert M. Bradley, Richard H. Backus,
James E. Craddock and Valerie Barber

Four variants of the Multiple Opening/Closing Net and Environmental Sensing System (MOCNESS) have been constructed to sample a broad size spectrum of oceanic animals -- microzooplankton to micronekton. The systems differ in mouth opening dimensions (ranging from 1/4 to 20 m²), the number of nets carried (from 5 to 20),

and the mesh size of the netting (from 64 μ m to 3.0 mm). A new electronics package enables an operator to send commands down a single conductor armored cable to open/close the nets and provides 12-bit resolution for the environmental (temperature, depth, conductivity) and net operation data (flow, netframe angle, net-bar release) which are transmitted up the cable to the deck unit at 2-second intervals. A microcomputer system, interfaced to the deck unit, calculates salinity, volume filtered by a net, net trajectory velocity, and vertical velocity. The data are printed out and stored on disc, and profiles of temperature and salinity versus depth are plotted during the course of the tow.

Analysis of the relationship between the geometry of the MOCNESS under tow and the past and present methods used to estimate the water filtered by a net revealed that significant bias is introduced when the ascent or descent angle of a net is disregarded. The bias is a function of the ratio of vertical velocity to net trajectory velocity and results in an underestimate of volume filtered while shooting a net and an overestimate while hauling.

Published in: Marine Biology, 87,
313-323, 1985.

Supported by: NSF Grant OCE83-17248.

WHOI Contribution No. 5856.

DEPARTMENT OF CHEMISTRY

Robert B. Gagosian, Department Chairman

CHEMISTRY

ORGANIC AND
BIOLOGICAL CHEMISTRY

SEASONAL VARIATIONS IN ^{15}N NATURAL
ABUNDANCE IN PARTICLES SINKING
TO THE DEEP SARGASSO SEA

Mark A. Altabet and Werner G. Deuser

Temporal variations in ^{15}N natural abundance have been used to study both nitrogen cycling and particle dynamics in the ocean. Changes in the $\delta^{15}\text{N}$ ($1,000 \times [({}^{15}\text{N}/{}^{14}\text{N})_{\text{sample}}/({}^{15}\text{N}/{}^{14}\text{N})_{\text{atmospheric N}_2} - 1]$) of particulate matter are related, in part, to variations in the input of nitrogen to the euphotic zone that has been observed to regulate the downward transport of particles. Here we report the first long-term data set for seasonal variations in the $\delta^{15}\text{N}$ of sinking particulate matter, sampled using a sediment trap. These variations co-vary with the magnitude of the particle flux. We proposed that the $\delta^{15}\text{N}$ of sinking particles is a monitor for NO_3^- flux into the euphotic zone during the formation of these particles on a timescale directly related to the magnitude of the particle flux.

Published in: Nature, 315, 218-219, 1985.

Supported by: NSF Grants OCE80-22990, OCE83-14013, OCE76-21280, OCE78-19813, OCE80-24130 and OCE82-19588.

WHOI Contribution No. 5913.

PARTITIONING OF PCBs IN MARINE SEDIMENTS

Bruce J. Brownawell and
John W. Farrington

Polychlorinated biphenyls (PCBs) are useful model compounds to study the physical-chemical processes which affect the biogeochemistry of hydrophobic organic compounds. In this study, two box cores from New Bedford Harbor, Massachusetts, were analyzed for PCBs. Measurements are reported for total PCBs and several individual chlorobiphenyls for both the sediments and interstitial waters. Concentrations of total PCBs were highly elevated in the pore waters and reached a maximum of 20.1 $\mu\text{g/L}$ at the Outer Harbor site. Results from these two cores combined with predictions from laboratory experiments indicate that most of the PCBs measured in interstitial waters are actually sorbed to organic colloids. The partitioning of

chlorobiphenyls between water column particulates and filtrate shows a greater importance of dissolved compounds due to lower concentrations of organic colloids. A simple three-phase equilibrium model involving colloids, dissolved phase, and chlorobiphenyls sorbed to particulate organic matter is presented to explain the observed partitioning.

Published in: Marine and Estuarine Geochemistry, Chapter 7, 97-120. A. C. Sigeeo and A. Hattori, eds. Lewis Publishers Inc., Chelsea, Michigan, 1985.

Supported by: A. W. Mellon Foundation; Education Office MIT/WHOI Joint Program in Oceanography; and NOAA Sea Grant Program Grants NA83-AA-D-0049 (R/P-13) and NA84-AA-D-00033 (R/P-17).

WHOI Contribution No. 5870.

INPUT OF EXCESS CO_2 TO THE SURFACE OCEAN
CALCULATED FROM STABLE CARBON ISOTOPE
RATIOS IN A BANDED JAMAICAN SCLEROSPONGE

Ellen R. M. Druffel and
Livia M. Benavides

Stable carbon and oxygen isotope ratios were measured in the skeleton of a living sclerosponge (*Ceratoporella nicholsoni*) collected from the surface waters off the northwest Jamaican coast. The resultant time histories of $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ reveal that the sclerosponge accretes aragonite in equilibrium with the surrounding sea water and dissolved inorganic carbon (DIC) and thus shows no evidence of a vital effect. The $\delta^{13}\text{C}$ record reveals a decrease from 1800 to 1972 of $0.50 \pm 0.15\text{‰}$. This decrease most likely represents the input of excess CO_2 from two sources: fossil fuel burning and reduction of forest/soil carbon reservoirs. The calculated decrease of $\delta^{13}\text{C}$ from fossil fuel CO_2 alone is less than that observed in the sclerosponge record. Using a model of the world carbon cycle and a deconvolution of our $\delta^{13}\text{C}$ data, we estimate that the amount of excess CO_2 from biotic sources is about one-third that from fossil fuel sources. This represents a net input of biospheric carbon between 1820 and 1972 to the atmosphere of 45 ± 25 gigatons C.

Supported by: NSF Grants OCE81-11954 and OCE83-15260.

WHOI Contribution No. 5914.

FOSSIL FUEL AROMATIC HYDROCARBON
BIOGEOCHEMISTRY IN THE MARINE
ENVIRONMENT: RESEARCH CHALLENGES

John W. Farrington

The state-of-the-art in research concerned with fossil fuel aromatic hydrocarbon biogeochemistry in the marine environment is discussed from the perspective of the new student or researcher entering this type of research. Topics discussed include physical chemical parameters, analytical chemistry, biogeochemical cycles, and bioavailability. Recommendations for future research are discussed briefly.

Published in: Proceedings NATO Advanced Study Institute: Strategies and Advanced Techniques for Marine Pollution Studies.

Supported by: DoE Contract EG-77-S-02-4392; EPA; A. W. Mellon Foundation; R. K. Mellon Foundation; and Mobil Foundation, Inc.

WHOI Contribution No. 5938.

SOME ASPECTS OF THE BIOGEOCHEMISTRY
OF POLYCHLORINATED BIPHENYLS IN THE
ACUSHNET RIVER ESTUARY,
MASSACHUSETTS, U.S.A.

J. W. Farrington, A. C. Davis,
B. J. Brownawell, B. W. Tripp,
C. H. Clifford and J. B. Livramento

Analyses of PCBs in sediment, water, and organisms by high resolution gas chromatographic quantitative determination of individual chlorobiphenyls revealed marked compositional differences in segments of the Acushnet River estuary ecosystem. Dramatic differences in chlorobiphenyl compositions in tissues of lobster, crab, and fish compared to compositions in industrial PCB mixtures released to the environment suggest that public health criteria based on PCB industrial mixture determinations should be revised. Predictions of bioconcentration based on K_{ow} of chlorobiphenyls are of limited accuracy for several chlorobiphenyls for which metabolism or membrane transfer selectivity are apparently the major determinants in some organisms. The importance of understanding the biogeochemistry of individual chlorobiphenyls as toxic compounds and as model compounds for studies of biogeochemistry of organic matter in aquatic ecosystems is discussed briefly.

In press: Symposium on Estuarine and Marine Chemistry. M. Sohn, ed.
American Chemical Society.

Supported by: A. W. Mellon Foundation; Mobil Foundation; and NOAA, National Sea Grant Program Grants NA83-AA-D-00049 (R/P-13) and NA84-AA-D-00033 (R/P-17).

WHOI Contribution No. 6043.

"MUSSEL WATCH" - MEASUREMENTS OF
CHEMICAL POLLUTANTS IN BIVALVES AS ONE
INDICATOR OF COASTAL ENVIRONMENTAL QUALITY

J. W. Farrington, A. C. Davis,
B. W. Tripp, D. K. Phelps and W. Galloway

The utility of the bivalve sentinel organism approach to monitoring for some chemicals of environmental concern in coastal and estuarine areas has been evaluated by varied regional and national programs and research efforts during the past fifteen years. The extent and severity of coastal contamination by chemicals such as polychlorinated biphenyls, chlorinated pesticides, trace metals and plutonium has been assessed in several bivalve sentinel organism programs. Advantages and limitations of this approach are presented and discussed briefly within the context of both national and international efforts.

In press: "Symposium on Monitoring and Aquatic Ecosystems." American Society for Testing and Materials Special Technical Publication Series.

Supported by: IFIAS/ABC and U.S. EPA Contract 68-03-3193.

WHOI Contribution No. 6066.

EARLY DIAGENESIS OF AMINO ACIDS AND
ORGANIC MATTER IN TWO COASTAL
MARINE SEDIMENTS

Susan M. Henrichs and John W. Farrington

Surface sediments of Buzzards Bay, Massachusetts, are oxic to suboxic and are extensively bioturbated by deposit-feeding infauna, while sediments of the Pettaquamscutt River Estuary, Rhode Island, are reducing and overlain by anoxic bottom water. Sediments from these two sites were analyzed for total organic carbon and nitrogen, total hydrolyzable amino acids, dissolved free amino acids, and porewater dissolved organic carbon, ammonium, total carbon dioxide, and sulfide. Using these data, the early diagenesis of sediment organic matter in Buzzards Bay (BBP) and Pettaquamscutt River Estuary (PRE) is compared. Based on Berner-type model calculations,

tions, organic matter remineralization rates in the upper 10 cm of Buzzards Bay and Pettaquamscutt River Estuary sediments are similar, at 14 and 10 g C/m²·year, respectively. The surface sediment organic carbon accumulation rate at the two sites is also similar, 36 (BBP) and 30 (PRE) g C/m²·year. Thus, preservation of organic matter is not greatly enhanced by anoxic conditions in the Pettaquamscutt River. Total hydrolyzable amino acids made up 11 to 23% (BBP) and 50% (PRE) of the total carbon remineralized. Decomposition did not result in detectable changes in hydrolyzable amino acid composition at either site. Glutamic acid and β-amino-glutaric acid were major constituents of the sediment dissolved free amino acids. Dissolved free amino acid distributions in Buzzards Bay and Pettaquamscutt River sediments are probably the net result of production and consumption by bacteria. Macrofauna and adsorption to sediment are additional sinks for dissolved amino acids in Buzzards Bay sediments, but they do not appear to be responsible for the major features of the dissolved free amino acid distributions.

Supported by: NSF Grants OCE79-18665 and OCE77-26184 and ONR Contract N00014-79-C1171.

WHOI Contribution No. 5954.

ACCUMULATION, CYCLING AND LOSS OF AMINO ACIDS IN SALT-MARSH ECOSYSTEMS: BIOLOGICAL AND CHEMICAL MECHANISMS

Randall E. Hicks, Cindy Lee and Andrew C. Marinucci

We investigated the source and composition of protein-bound and free amino acids during the decomposition of *Spartina alterniflora* in laboratory percolators and in a field experiment in the Great Sippewissett Marsh (Falmouth, MA). In the percolator experiments, free amino acids (30% of leached N) were leached from *S. alterniflora* litter within a few days and used quickly by microbes. Bacterial activity was responsible for recycling about 60% of the nitrogen leached from litter before it was lost. The composition of free amino acids changed during the leaching process, with Glu, Ala, Ser, and Asp the major amino acids lost. Although protein (15% of leached N) was also rapidly leached, it did not appear to be rapidly used by microbes. The composition of the protein amino acids changed during 16 days of leaching in the active percolator, with Asp, Gly, Ala, and Glu the major amino acids lost. Suspended bacterial mass likely accounted for 10-30% of the total

protein nitrogen lost from microbiologically active percolators. In the in situ marsh experiment, bound amino acid concentration (41-69% of total N) and composition in the litter remained constant after an initial leaching period. Asp, Gly, Ala, and Glu were the major amino acids present. Absolute increases in microbial protein did not account for the increase in total litter nitrogen which occurs during decay. Similarly, the adsorption of ammonium to *S. alterniflora* litter was not responsible for this increase. Thus, the absolute nitrogen increase was most likely due to phenolic compounds forming complexes with nitrogenous compounds, although preferential resistance of layered structural proteins may also occur.

In press: Marine Ecology Progress Series.

Supported by: NSF Grants OCE84-02179, BSR82-17040 and DEB79-05127 and ONR Contract N00014-85-C0001.

WHOI Contribution No. 5948.

AMINO ACIDS AND AMINES IN MARINE PARTICULATE MATERIAL AND SEDIMENTS

Cindy Lee

The distribution of amino acids and amines in marine particulate matter and sediments reflects the balance between biological production and biological consumption. The major source of particulate amino compounds in the water column is the formation of phytoplankton biomass by photosynthetic processes in the euphotic zone. Phytoplankton take up inorganic nitrogen, for example, nitrate or ammonium, and convert it to organic amino compounds. A small percentage of the particulate material formed sinks to the sea floor and is the major source of amino compounds to the sediments. In both seawater and sediments, the major mechanism of loss of amino compounds is heterotrophic decomposition by microbes, zooplankton, or benthic macroorganisms.

Amino acids, the building blocks of protein molecules, make up the largest reservoir of organic nitrogen in most organisms. Amino acids have been one of the more frequently studied classes of organic compounds in the marine environment and account for about one-quarter of the particulate organic carbon and half of the particulate organic nitrogen in surface waters. By sinking in particles to the sea floor, amino acids can provide energy and nitrogen to benthic organisms. However, since they are more labile than other

carbon compounds present in particulate matter, they become a smaller percentage of total particulate organic carbon with depth in the water column. In sediments, amino acids can comprise from less than 1% to as much as 50% of the organic carbon and 10 to 100% of the organic nitrogen.

In press: Nitrogen Cycling in Coastal, Marine Environments. T. H. Blackburn and J. Sørensen, eds. Wiley.

Supported by: NSF Grant OCE84-2179 and ONR Contract N00014-85-C0001.

WHOI Contribution No. 6045.

BIOGEOCHEMISTRY OF PUTRESCINE AND AMINO ACIDS IN OXIC AND ANOXIC WATERS OF A COASTAL SALT POND

Cindy Lee and Linda A. Hicke

Putrescine (diaminobutane) is found in all living cells and is also a decomposition product of ornithine and the protein amino acid arginine. We report here the concentration of putrescine and the rate constants of putrescine metabolism (respiration to CO₂ plus incorporation into cells) measured in a coastal salt pond. These values allowed us to calculate the net rates of putrescine respiration and incorporation. In our experiments, radio-labelled putrescine was quickly consumed in both oxic and anoxic waters. High rates of metabolism indicated that the putrescine supply rate must also be high since the concentration did not change dramatically. Residence times (<3h) and ratios of incorporation to metabolism (25-35%) of putrescine were similar to those of other organic substrates in similar environments. The ratio of incorporation to respiration rate was lower in anoxic waters than in oxic waters. During one experiment, a large increase in the rate of putrescine metabolism in shallow, oxic waters corresponded to a major phytoplankton bloom, suggesting that putrescine is supplied either directly by extracellular release or by rapid decomposition of phytoplankton protein in the epilimnion. Higher concentrations of putrescine and ornithine in the deeper waters suggest production there from decomposition of sinking phytoplankton protein or diffusive flux from the sediment.

Supported by: NSF Grant OCE80-24282 and ONR Contract N00014-85-C0001.

WHOI Contribution No. 5853.

CARBON-ISOTOPE FRACTIONATION AND CHANGES IN THE FLUX AND COMPOSITION OF PARTICULATE MATTER RESULTING FROM BIOLOGICAL ACTIVITY DURING A SEDIMENT-TRAP EXPERIMENT IN LAKE GREIFEN, SWITZERLAND

Cindy Lee, Judith A. McKenzie and Michael Sturm

Sediment traps were deployed in Lake Greifen, Switzerland for two weeks during May and June, 1983. We measured total particulate matter, organic carbon, organic phosphorus, and amino acids in the sediment trap material and stable carbon isotope ratios, dissolved free amino acids, and total suspended particle concentration in water samples. These measured parameters varied dramatically, and in combination, clearly reflected changes in environmental conditions and biological productivity over short time periods. The total particulate flux measured in opened and closed traps suggested that loss of material from unpoisoned sediment traps due to zooplankton heterotrophy can be extensive in the euphotic zone.

Changes in the oxygen and suspended particle concentrations indicated that productivity was lower during the colder, windier period at the beginning of the experiment, but significantly higher during a later, warmer period. SEM inspection of the trap particles indicated that allochthonous mineral debris was the major component of the material caught early in the experiment, suggestive of an input from resuspended sediments. Later, large newly-formed calcite crystals were prevalent in the traps, presumably precipitated because of the removal of CO₂ by increased photosynthesis during this period. During the period of sediment resuspension, the flux of total particulate material and total amino acids was highest near the lake bottom. In the surface waters, there was a peak in particulate flux during the later trap collection periods when productivity was higher.

Supported by: ONR; NSF Grants OCE83-00018 and OCE84-2179; and the Swiss National Science Foundation (Limnogeology Project).

WHOI Contribution No. 5998.

CHRONOLOGY OF CHOLELITHIASIS

Henry Y. Mok, Ellen M. Druffel and William M. Rampone

We investigated the chronology of gallstones using carbon-14 released into the environment during nuclear weapons

testing as a tracer. Radiocarbon determinations on 59 samples of gallbladder and ductal stones were performed and the ages of the stones correlated with dates of onset of symptoms and other clinical data. In 11 symptomatic patients, none developed symptoms or complications until at least 2 years after stone formation began, the mean period being $8.0 \pm \text{SD } 5.1$ yr. There was further delay between initial stone formation and cholecystectomy (11.7 ± 4.6 yr). Growth rate of stones from symptomatic (2.6 ± 1.4 mm/yr) and 4 asymptomatic (2.6 ± 1.1 mm/yr) patients was similar. Multiple gallstones from individual patients either were formed simultaneously, or the smaller stones developed later. Studies of 2 ductal stones showed that one had the same age as cholelithic stones; the other, removed 2 years after cholecystectomy, apparently grew in the common duct. In conclusion, the chronology of gallstones, including initial data of formation, growth rate, and latency period between stone formation and occurrence of significant symptoms was delineated using this methodology.

Supported by: NSF Grants OCE79-17652 and OCE81-11954.

WHOI Contribution No. 6102.

LIPID COMPOSITION OF THE PELAGIC CRAB *Pleuroncodes planipes*, ITS FECES, AND SINKING PARTICULATE ORGANIC MATTER IN THE EQUATORIAL NORTH PACIFIC OCEAN

Stuart G. Wakeham and
Elizabeth A. Canuel

Fecal pellets from the pelagic crab *Pleuroncodes planipes* comprised a significant part of the particulate organic matter collected in a sediment trap deployed at the bottom of the mixed layer in the eastern tropical north Pacific Ocean. The non-polar lipids of fresh fecal pellets of *P. planipes* were compared to lipids in the sediment trap material, in mixed zooplankton which may comprise the diet of the crab, and in the crab itself. Hydrocarbons, wax esters, triacylglycerols, steroidal alcohols, steroidal ketones, and fatty acids were determined by capillary gas chromatography and gas chromatography/mass spectrometry. Significant modification of dietary lipid apparently occurs within the gut of the crab and this is reflected in the non-polar lipid composition of the sediment trap material. Labile dietary fatty acids are preferentially depleted and sterols preferentially enriched in the fecal pellets and trap material relative to the zooplankton and crab. In addition, nuclear saturated and unsaturated 3-keto-

steroids and unsaturated steroidal hydrocarbons were detected in the crab, its feces, and in the sediment trap particulate material.

Supported by: ONR Contract N000014-82C-0071 and NSF Grant OCE80-3200.

WHOI Contribution No. 6097.

ORGANIC MATTER IN LEG 96 SEDIMENTS - CHARACTERIZATION BY PYROLYSIS

Jean K. Whelan and Martha Tarafa

Sediments from DSDP Sites 615, 617, 618, 619, and 620-623 were subjected to pyrolysis. The sediments are immature with respect to petroleum generation as determined by production index values of less than 0.1 and Tmax values of 460-480°C. The amount of pyrolyzable organic matter was moderately low as compared to typical petroleum source rocks. The immature organic matter present does not appear to contain a significant proportion of woody material as shown by low gas generating potential. Typical overbank sediments from Sites 617 and 620 generally show higher P2 values (500-800 ug hydrocarbon per g dry weight sediment) than typical channel-fill sediments from Sites 621 and 622 (P2 = 450-560 ug/g). Tmax for both types of sediment remained very constant (462-468°C) with a slight elevation (+15°C) occurring in samples containing lignite. The highest P2 values occurred in sections described as turbidites. Very low P2 values (about 50 ug/g) occurred in sands. P2 values for shallower sections of basin Sites 618 and 619 tended to be higher (900-1000 ug/g) and decreased in deeper more terrigenous sections of Site 619. Preliminary experiments indicate that microbiological degradation of sediment organic matter causes a decrease in P2. Pyrolyzable organic matter from lower fan Site 623 appears to increase with depth in two different sediment sequences (40-85 m and 95-125 m sub-bottom). Organic matter type, as shown by pyrolysis capillary gas chromatography (GC) patterns, was generally the same throughout the well, with much more scatter occurring in the deepest sections (130-155 m sub-bottom). One major and two minor organic matter types could be recognized in both fan and basin sites drilled on Leg 96.

In press: Initial Reports DSDP, Vol. 96.

Supported by: NSF Grant OCE82-00485.

WHOI Contribution No. 6028.

PHENOLIC AND LIGNIN PYROLYSIS PRODUCTS
OF PLANTS, SESTON, AND SEDIMENT IN A
GEORGIA ESTUARY

Jean K. Whelan, Martha E. Tarafa
and Evelyn B. Sherr

Phenolic and lignin pyrolysis products measured in plants, seston, and sediment in a Georgia estuary together with isotopic data suggest that vascular plant material is present in estuarine organic matter pools. The pyrolysis products together with isotopic patterns of this plant material do not resemble those obtained from *Spartina*. The pyrolysis-GC-MS data also gave indications of changes in distribution of methoxy phenolic compounds incoming from plant materials to soils and seston, which could be due to either degradation processes or to a change in source in seston and sediments. These phenolic and methoxyphenolic pyrolysis products have generally not been detected to date in either surface or sub-surface deep ocean sediments from several areas of the world. The combination of isotopic data, together with lignin and higher plant pyrolysis products, appears to provide a useful method of determining plant sources of organic matter in estuaries.

In press: "Estuarine & Marine
Chemistry," Adv. in Chem Series.
M. Sohn, ed.

Supported by: NSF Grant OCE82-00485.

WHOI Contribution No. 6055.

R A D I O C H E M I S T R Y

SCLEROSPONGE GROWTH RATE AS DETERMINED
BY ^{210}Pb AND $\Delta^{14}\text{C}$ CHRONOLOGIES

Livia M. Benavides and
Ellen R. M. Druffel

Measurements of bomb-produced radiocarbon and ^{210}Pb provide concordant estimates of the growth rate of the sclerosponge *Ceratoporella nicholsoni* collected from the surface waters of northern Jamaica. Radiocarbon measurements of older growth bands in the same specimen are similar to the time history of radiocarbon in coral bands from two other sites in the northwestern Atlantic. Furthermore, ^{210}Pb and stable Pb analyses reveal that the sclerosponge incorporates this element at much higher concentrations than corals.

In press: Coral Reefs.

Supported by: NSF Grant OCE81-11954.

WHOI Contribution No. 5955.

$^{239,240}\text{Pu}$ AND EXCESS ^{210}Pb INVENTORIES
ALONG THE SHELF AND SLOPE OF THE
NORTHEAST U.S.A.

Ken O. Buesseler, Hugh D. Livingston and
Edward R. Sholkovitz

Sedimentary Pu and excess ^{210}Pb inventory data are examined from a large number of sites along the U. S. North Atlantic shelf and slope. From these data, an estimate can be made of the magnitude and location of Pu and ^{210}Pb accumulation in this region. A major feature of the data is a decrease in the Pu and ^{210}Pb inventories with depth, which may reflect a decrease in the net scavenging of these elements offshore. When Pu and ^{210}Pb inventories are summed over water depths less than 4000 m in the North Atlantic shelf and slope region, the sediments can account for $24 \pm 8\%$ of the expected Pu and $83 \pm 15\%$ of the expected ^{210}Pb inputs. At water depths greater than 4000 m in this region, we find a greater deficiency in the measured inventories of both ^{210}Pb and Pu, which cannot be accounted for in the shallower sediments. This suggests that the NW Atlantic continental margin is not a major site of Pu or ^{210}Pb removal and storage, when compared to atmospheric, in situ, and lateral inputs of these radionuclides.

In press: Earth & Planetary
Science Letters.

Supported by: DoE Contracts
DE-AC02-83ER60172 and DE-AC02-
81EV10694 and Sandia National
Laboratories Contract 15-1034.

WHOI Contribution No. 5912.

DETERMINATION OF THORIUM CONCENTRATION IN
SEAWATER BY NEUTRON ACTIVATION ANALYSIS

C.-A. Huh and M. P. Bacon

A sensitive neutron activation analysis method has been successfully developed to determine ^{232}Th concentration in seawater. The method involves both preirradiation and postirradiation radiochemical separations. The isotopes were separated from the samples and purified during the preirradiation chemistry. ^{233}Pa was extracted and counted after the irradiation. Yields were

monitored with ^{230}Th and ^{231}Pa tracers. The separation and purification schemes include ion exchange chromatography and solvent extraction. By this method we have measured ^{232}Th concentrations in some seawater samples that are 1 order of magnitude lower than most previously reported values.

Published in: Analytical Chemistry, 57, 2138-2142, 1985.

Supported by: NSF Grant OCE83-14706.

WHOI Contribution No. 5878.

THORIUM-232 IN THE EASTERN CARIBBEAN SEA

C.-A. Huh and M. P. Bacon

The radiogenic Th isotopes (^{234}Th , ^{230}Th , and ^{228}Th) are produced in situ in the ocean from their dissolved progenitors (^{238}U , ^{234}U , and ^{228}Ra , respectively). These parent-daughter pairs have extensively been used to study the rate and mechanism of chemical scavenging, a process that is believed to be important in controlling the distributions and concentrations of many trace metals, such as Be, Al, Cr, Mn, Fe, Co, Cu, Pb and the rare earths. However, it is difficult to make useful direct comparisons between the distributions of the radiogenic Th tracers and those of trace metals, because their input pathways to the ocean are very different. To provide a link, one needs to determine the water-column distribution of the dominant isotope ^{232}Th , which is non-radiogenic and is thus delivered to the ocean by the same fluvial and aeolian pathways as most trace metals. However, with the exception of the near-bottom measurements recently reported by Nozaki and Horibe, little is known of the concentration level of ^{232}Th or its distribution pattern in the ocean. We report here the first profile showing the complete distribution of ^{232}Th in an oceanic water column from the Venezuelan Basin. The data were obtained by a sensitive neutron activation analysis method newly developed for this project. The profile shows relatively high concentrations in the upper 200 m with a maximum of 87 d.p.m./ 10^6 kg near the base of the mixed layer. Average concentrations in deeper water (2.7 d.p.m./ 10^6 kg) are uniform and atypically low compared with open-ocean deep waters, perhaps because of unusually rapid scavenging in the restricted basin. The source of the ^{232}Th in the surface waters is not known, but rivers appear to be more likely candidates than the atmosphere.

Published in: Nature, 316, 6030, 718-721, 1985.

Supported by: NSF Grant OCE83-14706.

WHOI Contribution No. 5923.

ANTHROPOGENIC RADIOTRACER EVOLUTION IN THE CENTRAL GREENLAND SEA

Hugh D. Livingston

The distribution patterns of several anthropogenic radiotracers in the Central Greenland Sea are presented together with a discussion of the significance of the changes in these patterns observed during the period 1972 to 1981. The radiotracers are the radionuclides ^3H , ^{137}Cs , ^{90}Sr , and $^{239,240}\text{Pu}$ - introduced to the region primarily as fallout from atmospheric nuclear weapons testing. Some ^{137}Cs is also derived from recent advective input of tracers of radioactive waste discharged to European coastal waters.

The observed patterns and their changes with time are discussed in the context of the source input history of each tracer, the physical properties of deep ventilation in the Central Greenland Sea gyre, and the chemical reactivity of the tracer. As conservative water tracers, the distributions with time of ^3H , ^{137}Cs , and ^{90}Sr can be explained in terms of their input histories and the resultant evolution of each tracer distribution by the purely physical mixing processes operating in the Greenland Sea. On the other hand, although physical mixing processes represent the major controls, the evolution of the $^{239,240}\text{Pu}$ distribution between 1972 and 1979 must be explained in terms of some Pu particle association and vertical scavenging by the net flux of particle populations sinking through the water column.

In press: Rit Fiskideildar, Journal of the Marine Research Institute, Reykjavik, Iceland.

Supported by: DoE Contract 73-C-02-3563 and NSF Grants OCE83-00491 and OCE84-02849.

WHOI Contribution No. 5990.

SEA WATER AND
GEOCHEMISTRY

THE REACTION OF SUPEROXIDE WITH NITRIC
OXIDE TO FORM PEROXONITRITE IN
ALKALINE AQUEOUS SOLUTION

Neil V. Blough and Oliver C. Zafiriou

Superoxide generated in aqueous alkaline solutions that are subsequently de-aerated reacts with nitric oxide to form the peroxonitrite anion in high yield. Reaction between hydrogen peroxide and nitric oxide does not form spectrophotometrically detectable amounts of peroxonitrite under these conditions.

Published in: Inorganic Chemistry,
24, 3502-3504, 1985.

Supported by: ONR Contract N00014-85-
C0001.

WHOI Contribution No. 5968.

TEMPORAL VARIABILITY OF LEAD IN THE
WESTERN NORTH ATLANTIC OCEAN

E. A. Boyle, S. D. Chapnick,
G. T. Shen and M. P. Bacon

In order to evaluate the ocean's response to decreasing leaded gasoline usage, new stable Pb and ^{210}Pb data have been obtained near Bermuda (June 1983 to December 1984). Concentrations of these tracers in the mixed layer were highly variable during the period of observations ($\pm 25\%$). From June through September, soluble eolian deposits accumulate in the shallow mixed layer because mixing and productivity are inhibited by the seasonal thermocline. In the fall, surface waters mix with upper thermocline waters and Pb concentrations decrease. In the winter, storms from the east coast of North America cause local episodes of high Pb and ^{210}Pb concentrations which are dispersed within less than two weeks by vertical and horizontal mixing. Pb/ ^{210}Pb ratios in surface waters are less variable and appear to have declined by a factor of 2.2 since 1979, similar to the 2.6-fold decrease in U.S. leaded gasoline consumption during this period. A substantial fraction (at least 10%) of gasoline lead is transported into the ocean. Pb concentrations in the upper thermocline may have declined by about 15% since 1979. The helium-tritium thermocline ventilation model of Jenkins (1980), coupled with boundary conditions appropriate

for Pb and ^{210}Pb , shows that Pb and ^{210}Pb profiles are dominated by lateral thermocline ventilation and, for stable lead, near-surface removal processes and time-dependent input. Vertical transport by particles is responsible for minor alteration of profiles which are dominated by isopycnal ventilation. Similar reasoning can account for the plutonium maximum in the thermocline of the North Pacific. Observations of Pb and other reactive species in winter surface outcrops of thermocline isopycnals would provide valuable constraints on chemical processes within the thermocline.

Supported by: NSF Grant OCE82-19583.

WHOI Contribution No. 6098.

RAPID MICROBIAL METABOLISM OF
NON-PROTEIN AMINO ACIDS IN THE SEA

J. J. Cole and C. Lee

The non-protein amino acids, β -alanine and γ -aminobutyric acid, frequently dominate the amino acid composition of deep-sea sediments. Preferential accumulation is most likely due to the slower decomposition of non-protein amino acids by microorganisms or to the preferential adsorption of non-protein amino acids by clay minerals. We investigated relative rates of heterotrophic uptake of alanine, β -ala, and γ -aba in sea water to see if there were different rates of microbial assimilation and respiration between these protein and non-protein amino acids. Heterotrophic uptake was rapid for all three amino acids with turnover times of hours in productive coastal waters and days in more oligotrophic open-ocean waters. Uptake of the non-protein amino acids was significantly slower than uptake of alanine, particularly in anoxic waters. However, the difference in uptake rates is probably not great enough to cause significant preferential accumulation of non-protein amino acids.

Supported by: NSF Grant OCE84-2179 and
ONR Contract No. N00014-85-C0001.

WHOI Contribution No. 6076.

SEASONAL AND INTERANNUAL VARIATIONS IN
DEEP-WATER PARTICLE FLUXES IN THE
SARGASSO SEA AND THEIR RELATION
TO SURFACE HYDROGRAPHY

W. G. Deuser

Six years of almost continuous sediment trapping in the deep Sargasso Sea,

with bimonthly sample recovery, reveal a pattern of annual flux variations as well as significant interannual differences. Spectral analysis of the data shows, however, that the temporal variability also has a large random component. Coherence among all constituent fluxes is very high, indicating that the composition of the sinking material is remarkably uniform throughout periods of greatly changing flux levels. The oxygen isotopic composition of tests of the epipelagic foraminifer Globigerinoides ruber intercepted by the trap at 3200 m represents a reliable recorder of near-surface hydrography one month prior to the tests' arrival in the trap. This tie between hydrographic changes at the surface and changes in quality and quantity of the sediment-trap samples provides a direct measure of sinking rate and reveals a very strong inverse relationship between surface temperature and the amount of material injected into deep water. As surface temperature controls depth of the mixed layer and thereby nutrient availability, that inverse relationship does not only relate primary sedimentation in the deep sea to the annual cycle of seasons at the surface but also confirms the close coupling of sedimentation, including that of abiogenic particles, to primary productivity in the open ocean.

In press: Deep-Sea Research.

Supported by: NSF Grants OCE76-21280, OCE78-19813, OCE80-24130 and OCE82-19588.

WHOI Contribution No. 5935.

RADIOCARBON IN PARTICULATE MATTER FROM THE EASTERN SUB-ARCTIC PACIFIC OCEAN: RESULTS FROM A SEDIMENT TRAP EXPERIMENT

E. R. M. Druffel, S. Honjo,
S. M. Griffin and C. S. Wong

Carbon isotope ratios were measured in organic and inorganic carbon of settling particulate matter collected by a sediment trap at Ocean Station "P" in the Gulf of Alaska from March to October, 1983. Dissolved inorganic carbon (DIC) in surface sea water samples collected during two different seasons in 1984 were analyzed using large gas proportional counters and revealed a minimum seasonal $\Delta^{14}\text{C}$ variation of 15‰. Results show that the $\Delta^{14}\text{C}$ of calcium carbonate sedimenting to the deep sea is the same as that measured in surface water DIC. In contrast, particulate organic carbon (POC) had significantly higher $\Delta^{14}\text{C}$ values (by 25-65‰) than that in surface

water DIC. Also, the $\delta^{13}\text{C}$ of the POC was markedly lower than previously reported values from other trap stations and marine particulate matter in general. These data support the observation by McAllister et al. (1960) that a considerable portion of the particulate carbon present in near surface waters at Ocean Station "P" is cellulose fibre from surrounding continental coasts. This suggests that a significant amount of the particulate organic carbon (POC) settling to the deep sea at this pelagic station is also of terrestrial origin, not strictly of marine origin as had previously been believed.

Supported by: NSF Grants OCE83-15260, OCE84-16632 and OCE83-09024.

Woods Hole Contribution No. 6053.

ORGANIC CHEMICAL POLLUTANTS IN THE OCEANS AND GROUNDWATER: A REVIEW OF FUNDAMENTAL CHEMICAL PROPERTIES AND BIOGEOCHEMISTRY

John Farrington and John Westall

Physical-chemical parameters derived from equilibrium partitioning are described and discussed within the context of biogeochemical cycles of pollutant organic chemicals in ground water and marine ecosystems. A few examples of actual field data are used to illustrate current state-of-knowledge regarding application of these parameters (K_{ow} , K_{oc} , BCF-biological concentration factors) and concepts to ground water, estuarine and open ocean ecosystems.

Further research and assessment considerations are discussed within the context of comparison of land and ocean disposal of wastes containing organic compounds of environmental concern.

In press: Scientific Basis for the Role of the Oceans as a Waste Disposal Option.

Supported by: Andrew W. Mellon Foundation; Richard King Mellon Foundation; and U.S. EPA Cooperative Agreement No. CR 8111894-01-1.

WHOI Contribution No. 6006.

THE AIR-SEA EXCHANGE OF PARTICULATE ORGANIC MATTER: THE SOURCES AND LONG-RANGE TRANSPORT OF LIPIDS IN AEROSOLS

Robert B. Gagosian

The sources, composition, transport pathways and fluxes of organic components in the atmosphere are just beginning to be

understood. Only recently have studies been undertaken to ascertain the processes controlling the spatial distributions of these substances. However, aside from methane and some halocarbons, relatively few measurements of vapor phase or particulate organic material have been made outside urban areas (for recent reviews see Duce, 1978; Simoneit and Mazurek, 1981; Duce and Gagosian, 1982; Buat-Menard, 1983; Duce et al., 1983a; Gagosian, 1983). In general, these studies have utilized the biomarker approach to assign terrestrial, marine, or anthropogenic origins to the organic components of the aerosols. This approach takes advantage of the unique molecular signatures or source "finger-prints" for various lipid compound classes of marine and terrestrial plants and animals to identify the sources of the organic substances in aerosols. Although these compounds represent a small portion of the organic matter in aerosols, they are excellent tracers for the sources and transformations of this material. This "tracer" approach for lipid class compounds is somewhat analogous to the use of natural and bomb fallout radionuclides in the study of oceanic and atmospheric processes.

In this chapter I present case studies from the multidisciplinary experiments of the Sea-Air Exchange Program (SEAREX) as examples of how the biomarker approach can be utilized to understand atmospheric processes controlling the distributions, sources, transport, and deposition of organic material in aerosols. Throughout the text I have attempted to emphasize what we have learned from these studies and what will be needed to answer questions concerning the processes of interest.

Supported by: NSF Grants OCE77-12914, OCE81-11947 and OCE84-06666.

WHOI Contribution No. 6094.

THE CHEMISTRY AND MINERALOGY OF
FERROMANGANESE ENCRUSTATIONS ON
ROCKS FROM THE SIERRA LEONE RISE,
THE EQUATORIAL MID-ATLANTIC RIDGE
AND THE NEW ENGLAND SEAMOUNT CHAIN

D. A. Goddard, G. Thompson,
E. J. W. Jones and H. Okada

The geochemistry and mineralogy of ferromanganese oxide encrustations on rocks dredged from the New England Seamounts in the Northwest Atlantic, the Sierra Leone Rise in the Eastern Equatorial Atlantic, and the Mid-Atlantic Ridge in the Equatorial Atlantic have been investigated using standard wet-chemical techniques, X-ray diffraction, and an electron micro-

probe. Mn/Fe ratios are close to unity in 17 samples from the shallow areas of the New England Seamounts, slightly less than unity in samples from the Sierra Leone Rise, while in the equatorial fracture zones ratios are appreciably less (average 0.75; 21 samples). Cu contents range from 0.02% to 0.2%. Ni also shows large variations (0.064% - 0.450%), the highest values occurring in deposits from the Vema Fracture Zone. Co shows a notable variation between the Northwestern and Equatorial Atlantic (0.048% - 0.135%, New England Seamounts; 0.355% - 1.010%, Sierra Leone Rise), with the highest values being found on phosphatized limestone on the upper parts of the Sierra Leone seamounts. The reasons for the variation in Co concentration is uncertain without growth rate data, but differences of a factor of 2 in the Co content of near surface waters in the northwestern Atlantic and equatorial Atlantic has been observed. Fine-scale variations in composition within the ferromanganese encrustations have been found using an electron microprobe, but it is clear that the nature of the substrate has little influence on the compositional changes. Todorokite is the predominant mineral present. δMnO_2 is common, while birnessite is relatively rare.

Supported by: NSF Grant OCE83-9582.

WHOI Contribution No. 6074.

FIELD AND LABORATORY STUDIES ON THE
ONTOGENY AND ECOLOGY OF SOME
GLOBOROTALIID SPECIES FROM THE
SARGASSO SEA OFF BERMUDA

C. Hemleben, M. Spindler,
I. Breiting and W. G. Deuser

The life habits of Globorotalia truncatulinoides (d'Orbigny) and Globorotalia hirsuta d'Orbigny have been investigated. These non-spinose planktonic foraminifers occur in high abundance in early spring and reproduce in the subtropical waters around Bermuda. Size measurements were made in order to trace test growth, and deep tows were taken to establish descent to deeper water. The observations and measurements revealed reproduction and juvenile habitat in the upper 200 m of the water column. Comparison of test sizes of sediment trap specimens with those of surface tow specimens demonstrates an increase due to addition of chambers as these species descend through the water column. Additional calcite is secreted on top of the normal wall when the tests reach water temperatures less than 8-10°C. The boundary of 8-10°C was established by temperature-controlled

experiments in the laboratory. Stable isotope investigations reveal a distinct shift from negative to positive $\delta^{18}\text{O}$ values between juveniles and adults, and the adults still show a vital effect of 0.25 - 0.5‰. The carbon isotope data suggest a change in feeding behavior or food source. The $\delta^{18}\text{O}$ values of adult specimens collected with plankton tows differ only by approximately 0.2‰ from those specimens obtained by sediment trap. This can be explained as being due to the addition of the calcite crust and/or one or two chambers.

Published in: Journal of Foraminiferal Research, 15, 254-272, 1985.

Supported by: NSF Grants OCE76-21280, OCE78-19813, OCE80-24130 and OCE82-19588.

WHOI Contribution No. 5882.

PRIMARY AND SECONDARY MIGRATION OF OIL

John M. Hunt

The dominant mechanisms of primary and secondary hydrocarbon migration are diffusion, in solution and as an oil or gas phase. The larger molecules move mainly by the latter two mechanisms with buoyancy as the driving force. The oils move laterally along bedding planes, unconformities, and sheet sands and vertically through permeability pathways along fractures, faults, mud volcanoes, and igneous intrusions. Heavy oils usually result either from the leakage of accumulations near the surface or from the weathering of conventional oils during migration and accumulation. A few heavy oils form directly from organic rich source rocks of early maturity. Some of the largest heavy oil accumulations in the world, such as the Faja of eastern Venezuela, have resulted from long distance migration covering a huge gathering area along the unconformities of foreland basins.

In press: AAPG Studies in Geology.

Supported by: DoE Contract EG-77-S-02-4392.

WHOI Contribution No. 5883.

^3H AND ^3He IN THE BETA TRIANGLE: OBSERVATIONS OF GYRE VENTILATION AND OXYGEN UTILIZATION RATES

William J. Jenkins

Isopycnal maps of ^3H - ^3He age (τ) with

about 100 km resolution have been obtained for a 1000 km scale area in the eastern subtropical North Atlantic. The mid-scale texture of the maps are consistent with isopycnal diffusivities of order $500 \text{ m}^2 \text{ s}^{-1}$. Analysis of the distributions within the context of advection-diffusion equations reveals that the larger scale ^3H - ^3He age gradients observed within the area are not seriously affected by mixing on those surfaces that outcrop in the region of Ekman downwelling. Thus isopycnal velocities can be estimated from $1/\nabla\tau$, but record only the velocity component normal to the outcrop. The velocities thus obtained agree well with geostrophic estimates, although the comparison is flawed by the fundamental mismatch in timescales between the two techniques. Backward extrapolation of the τ maps to zeroage outcrop positions indicate that the contribution of unventilated, older, recirculated water to the gyre flow above 600 m depth is small in this area (no more than 20%). A simple argument concerning the interaction of large scale flow with the topography of the depth of winter mixing shows that it is consistent with this process being a primary ventilation/subduction process for the subtropical gyre thermocline.

Advection-diffusion analysis of the AOU distributions on these surfaces indicates that oxygen utilization rates may be estimated using $\frac{\text{AOU}}{\tau}$ to an accuracy of order 10%. Such estimates appear consistent with previous work, and curvature in the AOU vs. τ relationship may be a reflection of a southeastward increase in surface primary productivity.

Published in: Journal of Physical Oceanography.

Supported by: NSF Grants OCE78-19815 and OCE81-17998.

WHOI Contribution No. 5924.

THE FLUX OF SYNTHETIC ORGANIC CHEMICALS TO THE DEEP SARGASSO SEA

Anthony H. Knap, Kandace Binkley
and Werner G. Deuser

The magnitude of flux of some synthetic organic chemicals to the open ocean is interesting from both an organic geochemical perspective as well as from an environmental health aspect. We have studied the deposition of polychlorinated biphenyls, chlordanes and dieldrin using a sediment trap in the Sargasso Sea over a two-year period. Previous studies of the flux of PCBs and some pesticides have inferred

open ocean flux from concentrations in euphotic zone particles and ocean sediments. We report here the first series of fluxes of these contaminants to the deep North Atlantic Ocean using sediment traps. The results indicate that these compounds were still important contaminants in the open ocean through 1980.

In press: Nature.

Supported by: British Petroleum, Inc.
and NSF Grants OCE76-21280,
OCE78-19813 and OCE80-24130.

WHOI Contribution No. 5956.

COSMOGENIC HELIUM IN A TERRESTRIAL IGNEOUS ROCK

Mark D. Kurz

High $^3\text{He}/^4\text{He}$ ratios in terrestrial samples are generally interpreted to indicate the presence of primitive or primordial gas. Despite the ubiquitous presence of cosmogenic noble gases in meteorites, cosmogenic isotopic signatures have never been observed in terrestrial samples and have for the most part been considered to be insignificant on the earth. This paper presents new helium isotopic measurements on a sample from the Kula formation of Haleakala volcano (Hawaii) that are best explained by an in situ cosmogenic origin for a significant fraction of the helium. Results from crushing and stepwise heating experiments, consideration of the exposure age of the sample at the surface and the cosmic ray fluxes strongly support this hypothesis. Although crustal cosmogenic helium has been previously theorized, this is its first unambiguous identification in a terrestrial sample.

Supported by: NSF Grant OCE-83-15270
and NASA Contract ECG-NAG-9-69.

WHOI Contribution No. 6059.

CHRONOLOGY OF SELECTED HYDROTHERMAL Mn OXIDE DEPOSITS FROM THE TRANSATLANTIC GEOTRAVERSE "TAG" AREA, MID-ATLANTIC RIDGE 26°N

C. Lalou, G. Thompson and P. A. Rona

Radiometric dating has been done on discrete layers in some hydrothermally deposited Mn-oxide (birnessite) samples from the TAG hydrothermal field on the Mid-Atlantic Ridge. Ages range from 16,000 to 4,000 years, with marked increases in activity noted about 15,000 and 7,000 years

ago. These observations, along with previously published data and inferences on different kinds of hydrothermal activity in the TAG field, suggest episodic, multistage hydrothermal events ranging from high temperature black smokers precipitating sulfides, to low temperature events precipitating Fe and Mn oxides over this whole time range. Black smokers are presently active. The location of the various deposits on the eastern wall of the median valley at this latitude suggests the high temperature events occur at deeper depths.

Supported by: NSF Grant OCE82-00812.

WHOI Contribution No. 6082.

OXYGEN ISOTOPE RATIOS OF THE PORE FLUIDS OF OCEAN SEDIMENTS NEAR THE COSTA RICA RIFT REVEAL A TIME HISTORY OF BASALT ALTERATION AND SEDIMENT DIAGENESIS

J. R. Lawrence, M. J. Mottl, M. Taviani,
Y.-H. Li and J. Rosenbaum

The oxygen isotope ratios of the pore fluids in the sediments from sites 501 and 504 of the Deep Sea Drilling Project near the Costa Rica Rift exhibit a large decrease with depth. Just above the basaltic basement this decreasing trend reverses sharply. Extensive lithification of the sediments to form limestones and cherts has taken place just above the basalts. The oxygen isotope ratios of the bulk carbonate sediments exhibit a slight decrease in oxygen isotope ratios with depth to the highly lithified sediments followed by a sharp decrease down to the basalts. The basalts are extensively altered to secondary minerals such as smectite.

Computer modelling of the oxygen isotope data using a paired set of diffusion and reaction equations reveals the likely time history of the basalt alteration and the lithification of the basalt sediments. The model results suggest the basalts have been undergoing closed system alteration for a period of time equaling 1.5 ± 0.5 my. The sediments were apparently lithified very recently in about the last 5000 years according to the model results.

Supported by: NSF Grant OCE83-00481.

WHOI Contribution No. 6008.

THE NITROGEN ISOTOPE GEOCHEMISTRY OF MARINE PARTICLES IN THE GULF OF MAINE

S. M. Libes and W. G. Deuser

The stable isotope geochemistry of nitrogen in plankton, particulate organic matter, and sediments was investigated in the Gulf of Maine. Below the euphotic zone, the isotopic content of particulate organic matter appears to reflect the effects of bacterial mineralization in the water column and at the sediment/water interface. Under oxic conditions, decomposition was observed to cause an increase in relative abundance of ^{15}N in the particles. Spatial and temporal homogeneity in the isotopic composition of the sediments was observed, suggesting that isotopic alteration at the sediment/water interface was influential in determining the relative abundance of ^{15}N in sedimentary organic nitrogen.

Supported by: NSF Grant OCE80-24442
and MIT/WHOI Joint Program.

WHOI Contribution No. 6088.

THE NITROGEN ISOTOPE GEOCHEMISTRY OF MARINE PARTICLES IN THE PERU UPWELLING AREA

S. M. Libes and W. G. Deuser

The stable isotope geochemistry of nitrogen in plankton, particulate organic matter, and sediments was investigated at four sites in the coastal region of Peru. Denitrification and microbial mineralization of particulate organic matter appear most influential in determining the isotopic content of particulate nitrogen in the water column. Isotopic alteration at the sediment/seawater interface associated with microbial decomposition of accumulating organic matter appears most influential in determining the $^{15}\text{N}/^{14}\text{N}$ ratios of the sediments.

Supported by: NSF Grant OCE80-24442
and MIT/WHOI Joint Program.

WHOI Contribution No. 6087.

THE GEOLOGICAL FORM AND SETTING OF A HYDROTHERMAL VENT FIELD AT 10°56'N, EAST PACIFIC RISE: A DETAILED STUDY USING ANGUS AND ALVIN

T. F. McConachy, R. D. Ballard,
M. J. Mottl and R. P. Von Herzen

A hydrothermal vent field, herein called the Feather Duster site, occurs on the eastern marginal high near the edge of a narrow (95 m) and shallow (15-20 m) axial graben, within an area dominated by sheet flows and collapse features. The sheet

flows are intermediate in relative age between young fluid flow lavas on the floor of the axial graben and older pillow (constructional) lavas on the marginal highs. Hydrothermal activity occurs in two zones within a 65 m by 45 m area. The main zone is located where a fissure system and sulfide-sulfate chimneys vent warm (9-47°C) and hot (347°C) hydrothermal fluids. Here, two mounds of massive sulfide totalling about 200 tons are forming. One occurs at the base of a 3 m high scarp which is the wall of a drained lava lake; the other is perched on top of the scarp.

As the vent field is located outside the axial graben, it is in a different setting from the majority of vent fields described by Hekinian et al. (1983b, c) at 13°N. However, it still is proximal to the neovolcanic zone and should share common plumbing systems with other hydrothermal deposits that are probably present in the axial graben at this latitude.

Supported by: NSF Grants OCE83-10175
and OCE83-09977.

WHOI Contribution No. 6018.

ACOUSTIC IMAGING OF HIGH-TEMPERATURE HYDROTHERMAL PLUMES AT SEAFLOOR SPREADING CENTERS

D. R. Palmer, P. A. Rona and M. J. Mottl

We explore the possibility of using active sonar techniques to acoustically image high-temperature "black smoker" hydrothermal plumes. As an initial step in identifying the dominant acoustic reflection mechanisms, we consider the Red Sea hydrothermal system. We infer, with qualifications, that the observed mid-depth reflections in the Red Sea hot brines are the result of scattering from suspended particulate matter primarily precipitated from the hydrothermal solutions and not of reflections from impedance contrasts or turbulent temperature fluctuations. We examine recent sonar images of a black smoker complex obtained at 11°N on the East Pacific Rise from DSV ALVIN which may show the presence of plumes. For the black smoker complex at 21°N on the East Pacific Rise estimates are obtained of the minimum detectable concentration of precipitates as a function of the range between the sonar and the plume boundary and of the maximum height above the chimney at which detection is possible for a sonar operating close to the plume boundary. These estimates are compared with measured concentrations. Some of the anticipated advantages of acoustic imaging are

discussed. We conclude that acoustic imaging techniques have the potential of providing a coherent framework for point sampling of physical and chemical properties of hydrothermal plumes and for determining the dynamics of their injection into the surrounding water mass.

Supported by: NSF Grant OCE83-10175.

WHOI Contribution No. 6007.

HYDROCARBON GEOCHEMISTRY AND
BIOLOGICAL MARKERS IN ORCA AND
PYGMY BASIN SEDIMENTS
(SITES 618 AND 619)

A. G. Requejo, Jean K. Whelan
and Paul D. Boehm

The C_{15+} hydrocarbon geochemistry of sediments from Sites 618 and 619 (Orca and Pygmy Basins) has been examined as part of a biogeochemical characterization of microbial activity and biological markers in Leg 96 sediments. Total hydrocarbon concentrations (13-78 ug/g dry weight) are elevated in comparison to those reported for Recent sediments from the Gulf of Mexico continental shelf, but there is little evidence that these sediments contain petroleum hydrocarbons originating from seepage. The presence of weathered fossil hydrocarbons is suggested, however, by the existence of an unresolved envelope feature in gas chromatograms of most sediments and also by the presence of C_{27} - C_{29} steranes and triterpanes. Normal alkane distributions are consistent with a predominant terrestrial organic input to these offshore basins. At Site 619 an increased terrestrial contribution below 113 m sub-bottom is indicated by an increase in the ratio of odd to even n-alkanes over the range C_{26} to C_{30} . Pristane/phytane ratios range between 0.97 and 1.74 which, in conjunction with the occurrence of significant concentrations of perylene (10-500 ng/g dry weight), suggest the prevalence of reducing depositional conditions at both sites. A hydrocarbon tentatively identified as a C_{25} multibranched compound similar to those found in Recent sediments was detected in most samples.

In press: Initial Reports of the Deep
Sea Drilling Project, Vol. 96.

Supported by: NSF Grant OCE83-00485.

WHOI Contribution No. 6101.

TEMPORAL CHANGES IN THE HYDROGRAPHY
AND CHEMISTRY OF THE CARIACO TRENCH

Mary I. Scranton, Frederick L. Sayles,
Michael P. Bacon and Peter G. Brewer

The Cariaco Trench has been considered a classic example of a marine anoxic basin for close to thirty years. Although most workers assume that the chemistry of the basin is constant, detailed data sets collected for hydrographic and nutrient parameters in 1973 and 1982 indicate strong temporal variations on a decadal time scale. Over the nine year period between the two cruises, deep water temperature increased by 0.06°C , salinity by about 0.01‰ , silica by about $14\mu\text{M}$ and hydrogen sulfide by about $15\mu\text{M}$. We have used a time dependent box model, including vertical eddy diffusion and a sediment flux term, to explain observed chemical variations. Geothermal heat flux explains only a small fraction of the observed temperature increase. Instead, deep water temperature and salinity increases are primarily the result of downward diffusion of heat and salt. Hydrogen sulfide profiles are also predicted fairly well by the model if a sediment-water flux of $2.76 \times 10^{-6} \mu\text{M cm}^{-2}\text{sec}^{-1}$ (measured using pore waters collected with the Woods Hole in situ Marine Probe) is used. Silica profiles cannot be adequately modelled, suggesting an additional source (other than flux from pore waters) of silica to the basin. We speculate this extra source may be dissolution of siliceous particles either within the water column or at the sediment surface before burial.

In press: Deep-Sea Research.

Supported by: NSF Grants DES75-02731,
OCE80-07949, OCE82-07517, OCE80-
24063, OCE81-24447 and OCE84-
12142.

WHOI Contribution No. 5940.

SEDIMENT SLUMPS IN THE MIDDLE AND
EARLY EOCENE OF DSDP HOLES 605 AND 613 -
CHEMICAL DETECTION VIA PYROLYSIS
TECHNIQUES

Martha E. Tarafa, Jean K. Whelan
and Gregory S. Mountain

Twenty-four sediment samples from DSDP Holes 605 (Leg 93) and 613 (Leg 95) from the New Jersey continental rise were analyzed by pyrolysis-gas chromatography. Twelve of these samples were also analyzed by pyrolysis-gas chromatography/mass spectrometry. The degree of sediment organic

matter preservation, as determined by these techniques, helped to distinguish slumped sediments from sediments that have not moved from their original place of deposition. Total levels of pyrolyzable organic material, as determined from pyrolysis-gas chromatography, were low in sediments that were not slumped, indicating that the organic material is highly degraded. Nitrogen- and oxygen-containing compounds were the primary compounds detected by gas chromatography/mass spectrometry (GCMS) analysis of the pyrolyzate of non-slumped sediments. Smaller amounts of aromatic compounds and branched alkanes were also present in some of these samples. In contrast, slumped sediments showed larger amounts of pyrolyzable organic matter as determined from pyrolysis-gas chromatography and better preservation of alkyl chains in the sediment organic matter as suggested by the presence of n-alkanes in GCMS analysis of the pyrolyzate. Better preservation of the organic matter in slumped sediments can be attributed to more moderate bioturbation by bottom dwelling organisms at the original site of deposition.

In press: Initial Reports of the Deep Sea Drilling Project, Vol. 95.

Supported by: NSF Grant OCE83-00485 and DoE Contract EG-77-02-S-4392.

WHOI Contribution No. 5983.

AXIAL PROCESSES ALONG A SEGMENT OF THE EAST PACIFIC RISE, 10°-12°N

G. Thompson, W. B. Bryan, R. Ballard, K. Hamuro and W. G. Melson

Axial segments of the East Pacific Rise are made up of individual volcanoes. Each volcano has a distinct magma composition and shows systematic variation in fractional crystallization with distance along axis from the central chamber. Hydrothermal venting, lava morphology and tectonics also vary along axis. Lavas erupted near transform faults, the tips of propagating rifts in overlapping spreading centers, and from near axis seamounts have different and variable compositions.

Published in: Nature, 318, 429-433, 1985.

Supported by: NSF Grant OCE84-09977.

WHOI Contribution No. 5962.

REACTION OF Br_2^- PRODUCED BY FLASH PHOTOLYSIS OF SEAWATER WITH COMPONENTS OF THE DISSOLVED CARBONATE SYSTEM

Mary B. True and Oliver C. Zafiriou

Br_2^- produced by flash photolysis of seawater decays by parallel first- and second-order reactions. The environmentally important exponential decay is a pseudo first-order reaction of Br_2^- with the carbonate/bicarbonate system in seawater. A chemical speciation model for the free ions and ion-pairs in seawater and in solutions at seawater ionic strength allowed us to measure the dependence of the pseudo first-order rate term, α , on individual CO_2 -containing species. A predictive equation based on reaction of Br_2^- with free CO_3^{2-} , NaCO_3^- and CaCO_3 ion pairs accounts for the mean seawater α at pH 8.1 within experimental uncertainty. The reaction product(s) are unknown.

Supported by: NSF Grants GA-35401, DES72-1553, OCE 77-09381 and OCE 84-17770.

WHOI Contribution No. 6035.

GEOCHEMISTRY OF VOLATILE ORGANIC COMPOUNDS IN SEAWATER

Stuart G. Wakeham, Elizabeth A. Canuel and Peter H. Doering

A series of ten radiotracer experiments were conducted in controlled experimental ecosystems (mesocosms) to investigate the behavior of volatile organic compounds (VOC) in seawater. Time-series measurements of the redistribution of ^{14}C -activity within several major pools - dissolved, particulate, intermediate metabolite, and CO_2 - in the ecosystem made possible an evaluation of the rates of processes - volatilization, biodegradation, sorption and sedimentation - acting to remove VOC from seawater in summer. The behavior of the model ^{14}C -VOC fell into three categories. Aromatic hydrocarbons (benzene, toluene, naphthalene) were subject to both volatilization and biodegradation, with mineralization dominating in summer. Chlorinated C_2 -hydrocarbons (tetrachloroethylene) and chlorinated benzenes (chlorobenzene, 1,4-dichlorobenzene, and 1,2,4-trichlorobenzene) were affected only by volatilization and were relatively resistant to biodegradation. Of all the model VOC studied, only aliphatic hydrocarbons (decane and octadecane) were sorbed onto suspended particulate matter; however, the primary route of loss from the water column appeared to be biodegradation rather than

sedimentation. The mesocosm-derived removal rate constants were then applied to estimate summer VOC residence times in Narragansett Bay, Rhode Island of about 1 day for aromatic hydrocarbons, 1 week for the chlorinated VOC and about 1 day for aliphatic hydrocarbons. Residence times in winter might be on the order of 1 week for all VOC.

Supported by: NOAA Grant 81RAD00015 and NSF Grant OCE84-16203.

WHOI Contribution No. 6095

THE BEHAVIOR OF ALIPHATIC HYDROCARBONS IN COASTAL SEAWATER: MESOCOSM EXPERIMENTS WITH ^{14}C -OCTADECANE AND ^{14}C -DECANE

Stuart G. Wakeham, Elizabeth A. Canuel and Peter H. Doering

^{14}C -octadecane and ^{14}C -decane were used in controlled ecosystem experiments to quantify the fate of low molecular weight, volatile aliphatic hydrocarbons in estuarine seawater. Both model compounds are rapidly sorbed onto suspended particulate matter, but biodegradation rather than sedimentation appears to be their major fate. Approximately 60-70% of the alkanes were mineralized in the water column within about a week. Volatilization is relatively minor, accounting for the loss of only about 15% of both hydrocarbons. The experimental data were used to predict summer residence times of about 0.6 and 0.4 days for octadecane and decane, respectively, in Narragansett Bay.

In press: Environmental Science and Technology.

Supported by: NOAA Grant NA81RAD00015.

WHOI Contribution No. 5893.

C1-C8 HYDROCARBONS IN SEDIMENTS FROM THE LOWER CONTINENTAL RISE, DSDP SITE 603

Jean K. Whelan and Christine Burton

Small amounts of C1-C8 hydrocarbons were detected in continental rise sediments from DSDP Site 603. Organic-lean sections contained only C1-C3 compounds believed to have migrated from organic-rich sections. Heavier (C4-C8) hydrocarbons were found only in organic-rich sections. Restricted and sporadic distribution of C4-C6 compounds in 0-1100 m sub-bottom sediments suggest low temperature (<20°C) biological/chemical generation processes. Increased C4-C8 concentrations and complexity, in-

cluding unusually high levels of xylene, were detected in two deeper cretaceous sections (34-2-134 and 81-3-120). This behavior, which was not observed in 17 other samples from sub-bottom depths greater than 1100 m, is similar to that observed in immature surface sediments from the geothermally active Guaymas Basin (Gulf of California) area.

In press: Initial Reports of the Deep Sea Drilling Project, Vol. 93.

Supported by: DoE Contract EG-77-02-4392.

WHOI Contribution No. 6051.

EVIDENCE FOR SULFATE REDUCING AND METHANE PRODUCING MICRO-ORGANISMS IN SEDIMENTS FROM SITES 618, 619 AND 622

Jean K. Whelan, Ronald Oremland, Martha Tarafa, Richard Smith, Robert Howarth and Cindy Lee

Radiolabelled products were formed from labelled substrates during anaerobic incubation of sediments from Sites 618, 619, and 622. One set of experiments formed $^{14}\text{CO}_2$, $^{14}\text{CH}_4$, and H_2^{35}S from 2- ^{14}C -acetate and ^{35}S -sulfate; a second set formed $^{14}\text{CH}_4$ from ^{14}C -methylamine or ^{14}C -trimethylamine. Levels of $^{14}\text{CO}_2$ and $^{35}\text{S}^{2-}$ formed were 2-3 orders of magnitude greater than $^{14}\text{CH}_4$. Production of $^{14}\text{CH}_4$ by DSDP sediments was 4-5 orders of magnitude less than that formed by anoxic San Francisco Bay sediment. However, incubation of Site 622 sediment slurries under H_2 demonstrated production of small quantities of CH_4 . These results indicate that DSDP sediments recovered from 4 to 167 m sub-bottom (max. age ~160,000 years) harbor potential microbial activity which includes sulfate-reducers and methanogens. Analysis of pore waters from these DSDP sites indicates that bacterial substrates (acetate, methylated amines) were present.

In press: Initial Reports of the Deep Sea Drilling Project, Vol. 96.

Supported by: NSF Grant OCE82-00485.

WHOI Contribution No. 6029.

WAVELENGTH-DEPENDENT QUANTUM YIELD OF OH RADICAL FORMATION FROM PHOTOLYSIS OF NITRITE ION IN WATER

Oliver C. Zafiriou and Roland Bonneau

The quantum yields of formation of hy-

droxyl radicals Φ_{OH} in aqueous nitrite solutions have been measured at four wavelengths in the long-wavelength absorption bands by laser flash photolysis. The OH radical was scavenged quantitatively by added bromide or thiocyanate ions to yield Br_2^- or $(SCN)_2^-$ ion-radicals. At wavelengths above 350 nm the quantum yield is about 0.02, while it is about 0.06 below 340 nm. The quantum yields do not depend on pH, pO_2 , ionic strength, or scavenger concentration, and increase only slightly with increasing temperature. These results are interpreted in terms of the mechanism of nitrite photolysis and their implications for the solar photolysis of nitrite in natural waters.

Supported by: NSF Grants OCE81-09381 and OCE85-17770.

WHOI Contribution No. 5967.

INTERFERENCES IN ENVIRONMENTAL ANALYSIS OF NO BY (NO + O₃) DETECTORS: A RAPID SCREENING TECHNIQUE

Oliver C. Zafiriou and Mary B. True

The NO + O₃ chemiluminescence detector (NO-CLD) offers a suitable sensitivity, portability, and cost compromise for field studies of NO_x. However, its selectivity for NO is not inherent, so empirical validation of this factor in different types of gas samples, particularly those rich in other trace components, is necessary. Here we report a simple, practical and stringent procedure based on determination of relative reaction rates of NO and sample with O₃ to detect interferences. Using the screening technique, we find significant interferences in gases emitted or stripped from some marine environments.

Supported by: NSF Grants OCE83-15614 and OCE83-00022.

WHOI Contribution No. 5966.

CONSEQUENCES OF OH RADICAL REACTION IN SEAWATER: FORMATION AND DECAY OF Br_2^- ION-RADICAL

O.C. Zafiriou, M.B. True and E. Hayon

The interaction of OH radical with seawater yields oxidized bromide species. The identity of the oxidized bromide species and its subsequent reactions have been studied by extensive flash photolysis experiments and also by pulse radiolysis. OH appears to give a nearly quantitative

yield of the dibromide ion-radical in seawater. This radical decays by parallel first- and second-order reactions, the latter process being well-known but irrelevant in nature. The former process involves reaction with some components of the carbonate system in seawater, resulting in decay rates for the dibromide ion-radical of roughly 2000-3000 s⁻¹ in seawater at pH 8 (halftimes of ca. 300 microseconds).

Supported by: NSF Grants GA-35401, DES72-1553, OCE79-09381 and OCE84-17770.

WHOI Contribution No. 6019.

DEPARTMENT OF GEOLOGY AND GEOPHYSICS

David A. Ross, Department Chairman

AUSTRALIA--A STABLE PLATFORM
FOR TIDE-GAUGE
MEASUREMENTS OF CHANGING SEA LEVELS?

D. G. Aubrey and K. O. Emery

Twenty-five tide-gauge records non-uniformly distributed along the coast of Australia were used to evaluate the potential of Australia as a stable platform from which to measure future changes in sea levels. The spatial and temporal variabilities of relative sea levels were defined using a multivariate analytical tool (eigen-analysis) on thirteen of these stations. Low-frequency (period 20 years and greater) relative sea levels are believed to reflect the combined effects of subsidence due to sediment and water loading, subsidence due to thermal cooling of oceanic crust, and emergence along a convergent plate boundary. Global eustatic sea-level rise cannot be identified unambiguously from these data. The straight average rate-of-rise of relative sea level around Australia is 1.3 mm/year (submergence) with general submergence in the south (at an average rate of 1.8 mm/yr) and emergence in the north (0.5 mm/yr, the latter an average of two stations).

Higher-frequency fluctuations in relative sea levels show relative peaks at 20, 12, and 6 years, with significant energy at higher frequencies as well. Higher frequency fluctuations correlate with patterns of El Nino/Southern Oscillation. During El Nino events, yearly-averaged sea levels of Australia fall, although not all local minima in relative sea levels correspond with El Ninos. The resultant drop in relative sea levels represents a balance between lower sea levels due to raised atmospheric pressure with coincident lowered water temperatures, and higher steric sea levels due to increased precipitation and runoff (for those stations located in estuaries).

Eustatic ("global") sea-level behavior cannot be identified unambiguously from these observations. Tectonic effects combined with isostatic response of the continental margin to sediment and water loading complicate the low frequency sea-level response. Australian sea levels cannot be used to define unambiguously past eustatic sea-level history because of considerable spatial non-homogeneity in relative sea-level rise, but they may be useful for monitoring possible future increases in rate of global sea-level rise.

Supported by: NOAA Sea Grant NA83-AA-

WHOI Contribution No. 5973.

PALEOGENE CALCAREOUS NANNOPLANKTON
BIOSTRATIGRAPHY OF NORTHWESTERN EUROPE

Marie-Pierre Aubry

The classic Paleogene stages (Thanetian, Cuisian, Lutetian, Bartonian, Ludian and Stampian) defined in the epicontinental deposits of the Anglo-Paris Basin(s) are placed within a standard biostratigraphic framework based on an analysis of their calcareous nannoplankton floras. Relatively precise biostratigraphic correlations can be made with some chronostratigraphic units (e.g., Lutetian), while biostratigraphic resolution of others (e.g., Ludian) is limited. Important hiatuses are recognized between certain chronostratigraphic units. Only the base of the Lutetian (late NP14) and Bartonian (mid-NP16) stages can be precisely determined in terms of calcareous nannoplankton zones. With the recent study of the magnetic polarity history of the Paleogene of southern England and recent advances in magnetobiostratigraphic correlations in deep-sea cores, it is possible to interpret the Paleogene history of the Anglo-Paris Basin(s) in a synoptic global framework in which paleomagnetic stratigraphy provides the chronologic element, and eustatic variations provide the dynamic element. Redefinition of the boundaries of the standard Paleogene chronostratigraphic units of Northwestern Europe within, rather than at, the boundaries of (i.e., at unconformities) eustatically-controlled depositional cycles would result in more precise correlations in terms of standard calcareous nannoplankton biostratigraphy.

In press: *Palaeogeography, Palaeoecology, Palaeoclimatology*. Elsevier.

Supported by: A consortium of oil companies.

WHOI Contribution No. 6000.

A REPORT PREPARED FOR WORKSHOP A4:
NEOGENE CHRONOLOGY AND
CHRONOSTRATIGRAPHY - NEW DATA BASED ON
RECENT ISOTOPIC, PALEOMAGNETIC,
AND BIOSTRATIGRAPHIC STUDIES

W. A. Berggren

One of the main subjects on the pro-

gram of the VIIIth RCMNS Congress in Budapest (15-22 September 1985) is Topic A: Relative and Numerical Time Scales. In addition to the symposium to be held in the plenary session, there will be a complementary Workshop A4: Neogene Chronology and Chronostratigraphy - New Data, organized by F. F. Steininger and W. A. Berggren. This report has been prepared for presentation at the workshop. Its main purpose is to bring together data which has become available only recently dealing with Neogene isotopic and/or magneto-chronology. The data are from both marine and terrestrial sequences and provide a valuable source of information in continuing efforts to refine Neogene geochronology. However, as is often the case in any area of scientific research, there are conflicting aspects to some of the data and prospective users would do well to heed the Roman interdiction: caveat emptor. Some of these conflicts are discussed in the papers cited here and the interested reader is urged to consult primary sources.

Original figures and tables (and their captions) are included in this report for ease of reference but new numbers have been assigned here for the sake of continuity in references to the text.

Published in: Proceedings of the
8th Congress Mediterranean Neogene
Stratigraphy.

Supported by: NSF Grant OCE84-17040.

WHOI Contribution No. 6009.

RESOURCE POTENTIAL OF THE WESTERN NORTH ATLANTIC BASIN

W. P. Dillon, F. T. Manheim, L. F. Jansa,
G. Palmason, B. E. Tucholke
and R. S. Landrum

The principal geologic resources of the western north Atlantic Basin probably include petroleum, ferromanganese nodules and crusts, phosphorite, mid-ocean-ridge sulfides, and geothermal energy. Of these, only geothermal energy has been developed, at present, and some of the others never may be developed. In our opinion, the most valuable resource of the western North Atlantic ultimately will be petroleum, once techniques of drilling and completing wells in deep water are perfected.

In press: "The Geology of North America: The Western Atlantic Region."
P. R. Vogt and B. E. Tucholke,
eds. Geological Society of America.

Supported by: The Mellon Senior Study

Award.

WHOI Contribution No. 6099.

GLACIAL REBOUND AND RELATIVE SEA LEVELS IN EUROPE FROM TIDE-GAUGE RECORDS

K. O. Emery and D. G. Aubrey

Relative sea levels recorded by tide gauges during the past century in northern Europe are dominated by isostatic readjustment of the land following the latest deglaciation of Scandinavia and Scotland. Maximum relative uplift of the land is centered near the northern Gulf of Bothnia (at a rate of 6-7 mm/year), with a smaller secondary maximum over Scotland (also at a rate of 6-7 mm/year). Although there probably is a relaxing peripheral bulge surrounding the regions of maximum uplift, such a former bulge is poorly defined by coastal tide gauges; in the North Sea evidence for sinking of a former peripheral bulge of glacial origin is complicated by post-Carboniferous basin deepening with sediment loading and possible rejuvenation associated with glaciation. Other data (gravity, radiocarbon, geomorphology) support the interpretation that glacial isostasy controls the structure of relative sea-level change. Included in this pattern of relative rise of land is a eustatic signal that biases the estimates of glacial rebound. Such a eustatic signal could not be isolated from the isostatic signal using the present data, but glacial isostasy clearly is a major control for relative sea levels of the region.

In Press: Tectonophysics.

Supported by: NOAA Sea Grants NA80-AA-D-0077 (R/B-54) and NA83-AA-D-0049 (R/B-54); the Coastal Research Center, WHOI; and the Ocean Industry Program, WHOI.

WHOI Contribution No. 5880

RELATIVE SEA-LEVEL CHANGE FROM TIDE-GAUGE RECORDS OF WESTERN NORTH AMERICA

K. O. Emery and D. G. Aubrey

Negligible success of investigators in relating tide-gauge records of the west coast of North America to eustatic changes of sea level is found to be due to tectonic movements of the land reference level beneath the tide gauges. The vertical tectonic movements are caused by horizontal movements of oceanic crustal plates. Sinking of 12 mm/yr at Cordova, Alaska, is associ-

ated with intense subduction at the east end of the Aleutian Trench; rising by 6 mm/yr at Skagway -- resistance to lateral crustal movement toward the filled trench; rising of 1 mm/yr. in southern Alaska -- uplift above slow subduction; little vertical movement between Sitka and Mendocino Fracture Zone -- translation and slow subduction including fracture zones; sinking of 1 mm/yr west of the San Andreas Fault -- translation; and sinking of 2 mm/yr along northwestern Mexico -- effects of cooling of late-rifted crust and only diagonal subduction. Superimposed on this tectonicism due to plate motion is broad scale isostatic adjustment (both rise and fall) resulting from deglaciation that by itself fails to account for regional variability.

Higher frequency (0.05 to 0.5 cpy) sea-level changes are associated with El Nino/Southern Oscillation events, as well as response to large scale pressure fluctuations and wind stress events.

Supported by: NSF Grant OCE85-1174; NOAA Sea Grant NA83-AA-D-00049; and the Coastal Research Center, WHOI.

WHOI Contribution No. 6058.

RELATIVE SEA-LEVEL CHANGES FROM TIDE-GAUGE RECORDS OF EASTERN ASIA MAINLAND

K. O. Emery and D. G. Aubrey

Records from 22 tide-gauge stations along the mainland coast of eastern Asia document low-frequency vertical movements of the land perhaps biased by unevaluated changes of sea level. The land is rising (relative to sea level) as much as 5 mm/yr in the areas of massifs and ancient foldbelts and subsiding as much as 9 mm/yr in areas of Cenozoic basins and foldbelts. Although the tide-gauge records are sparse, inferences from them are supported by the geologic stratigraphy and structure of the region and by raised and submerged sea-level terraces. Thus relative changes of sea level are heavily influenced here by tectonic and isostatic as well as eustatic factors, just as in Japan, Scandinavia, and North America where tide-gauge records are much more abundant. Higher frequency (2-25-year periods) sea-level fluctuations show broad peaks between 2 and 4 years, and near 10 years. Some of these fluctuations correlate with behavior of the Kuroshio Current, which along with freshwater inflow dominates the hydrography of the eastern Asian continental shelves. Observations of water mass fluctuations are too sparse to identify direct causes of all high-frequency variability.

In Press: Marine Geology.

Supported by: NOAA Sea Grants NA80-AA-D-00077 (R/B-54) and NA83-AA-D-00049 (R/B-54); the Coastal Research Center, WHOI; and the Ocean Industry Program, WHOI. WHOI Contribution No. 5874.

THE GEOLOGY OF THE OCEANOGRAPHER TRANSFORM: THE TRANSFORM DOMAIN

P. J. Fox, R. H. Moody, J. A. Karson, E. Bonatti, K. Crane, W. S. F. Kidd, D. G. Gallo, J. B. Stroup, D. J. Fornari, D. Elthon, P. Hamlyn, J. F. Casey, D. Needham and R. Sartori

Three dives in submersible ALVIN and four deep-towed camera lowerings have been made along the transform valley of the Oceanographer Transform. These data constrain our understanding of the processes that create and shape the distinctive morphology that is characteristic of slowly-slipping ridge-transform-ridge (RTR) plate boundaries. Our data suggest that the locus of strike-slip tectonism, called the transform fault zone (TFZ), is confined to a narrow swath (<4km) that is centered along the axis of maximum depth. The TFZ is flanked by the inward facing slopes of the transform valley. The lower portions of the valley walls are characterized by broad exposures of undisrupted sediment but at higher elevations the walls are made up of inward facing scarps and terraces of variable dimensions. Although the scarps have been badly degraded by mass wasting, there is no evidence to suggest that these scarps have accommodated significant amounts of strike-slip motion. Plutonic and ultramafic rocks are exposed on these scarps and the occurrence of this diverse assemblage on small throw faults indicates that the crust is thin and/or discontinuous in this environment. We suggest that this complex igneous assemblage is the product of anomalous accretionary processes that are characteristic of slowly-slipping RTR plate boundaries.

In press: Marine Geophysical Research.

Supported by: ONR Contracts N00014-80-C-0287, N00014-81-C-0820, N00014-80-C-0098-S.W. and N00014-80-C-0098-S.T.

WHOI Contribution No. 5992.

SEDIMENTATION, RESUSPENSION AND CHEMISTRY
OF PARTICLES IN THE NORTHWEST ATLANTIC

Wilford D. Gardner, John B. Southard
and Charles D. Hollister

Sediment traps were deployed to sample vertical fluxes of particulate matter both immediately above and within the nepheloid layer on the continental slope and rise of the western North Atlantic. The data from the traps are used to estimate the settling flux of particles and to attempt to distinguish between the primary flux (settling material from the upper water column) and the resuspended flux (settling material that has been resuspended from some region of the sea floor). From these data and from measurements of the net nepheloid standing crop of particles, estimates of the mean residence time for particles resuspended in the nepheloid layer are on the order of weeks to months from 15-500 m above bottom. Horizontal advection and diffusion are more important than vertical mixing in maintaining the upper portion of the nepheloid layer.

The estimated flux of Al to the North Atlantic as atmospheric dust is one to two orders of magnitude less than the primary flux of Al measured just above the nepheloid layer, yet the range of accumulation rates of Al measured on the sea floor with radioisotopes is close to the values we define as the primary flux. Horizontal transport of Al-rich particles (mostly aluminosilicates) must therefore be significant even above the nepheloid layer.

The size of 80%-90% of the particles collected in the traps both above and within the nepheloid layer was less than 63 μm . The mean size of particles trapped in the nepheloid layer was about 22 μm , and above the nepheloid layer, 11 μm . The particles were probably in large aggregates when they encountered the traps, but identifiable fecal pellets are only a small fraction of the material collected in the traps.

Between 6 and 15% of the primary production of particulate organic carbon in the euphotic zone was collected in floating sediment traps at the 100 m depth, indicating that most particulate organic carbon is recycled in the surface water. Only 2-3% of primary production of organic carbon was collected as primary flux 500 m above the sea floor. 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 core tops), it was found that elements associated with biogenic matter, such as Ca, Sr, Cu, and I, were carried preferentially by the rapidly falling particles. Once these par-

ticles reached the sea floor the concentration of those elements was decreased through decomposition, respiration, or dissolution. Dissolution appears to be rapid near or on the sea floor, because radiolarians, diatoms, and juvenile foraminifera were rare in core samples even though abundant in all traps. The dynamic nature of the nepheloid layer makes it possible for particles to be resuspended many times before they are finally buried, enabling sediment to be carried long distances from its origin. The recycling of particles near the sea floor may also increase dissolution of siliceous and carbonate matter.

Published in: Marine Geology, 65,
199-242.

Supported by: ONR Contracts N00014-74-C-0262 and N00014-75-C-0291.

WHOI Contribution No. 5875.

TECTONICS OF SHORT-OFFSET, SLOW-SLIPPING
TRANSFORM ZONES IN THE FAMOUS AREA,
MID-ATLANTIC RIDGE

Margaret R. Goud and Jeffrey A. Karson

ANGUS photographs and ALVIN observational data from Fracture Zones A and B on the Mid-Atlantic Ridge near 37°N were examined for structural and sedimentological indications of the area's tectonics. Both transform fault zones are characterized by volcanic rubble, breccias, chalks, and undisturbed sediments typical of slow-slipping transforms.

The photographic data consist of 16 camera-sled traverses from the FAMOUS Expedition using the ANGUS deep-towed camera system. These data cover several different morphotectonic provinces along the strike of both slow-slipping (2 cm/year) fracture zones. ALVIN data come from two dives in the central part of Fracture Zone B. The two fracture zones differ in their distribution of fractured and sheared chalks which indicate regions of strike-slip deformation along the transform. Evidence of shearing is confined to a very narrow region in the center of FZ A, whereas the zone of shear deformation is as much as 6 km wide across FZ B. Other differences include the morphology and depth of the transform valleys and their contiguous nodal basins and the extent of exposures of fresh-looking volcanic ridges in the nodal basin.

In Press: Marine Geophysical
Researches.

Supported by: NSF Grant EAR83-14951.

STABLE ISOTOPE STRATIGRAPHY AT THE
CRETACEOUS/TERTIARY BOUNDARY IN DENMARK

Michael A. Kaminski and Bjorn A. Malmgren

Carbon and oxygen isotope measurements were made in bulk sediments from two localities from the Danish-Polish Trough - Stevns Klint and Kjolby Gaard. Isotopic measurements on fine fraction, benthonic, and planktonic foraminifera were performed on samples from Kjolby Gaard.

Analysis of closely-spaced samples across the Cretaceous-Tertiary boundary reveal a large (2‰) positive oxygen isotope excursion coincident with the iridium anomaly in the Fish Clay, followed by large fluctuations in $\delta^{18}O$ in the basal Danian. Stable isotopes of carbon document a lightening across the C/T boundary. The shift towards lighter $\delta^{13}C$ values begins 0.75 m beneath the boundary clay at Kjolby Gaard and at Stevns Klint corresponds to the zone of low dinoflagellate abundance in the Danian. These $\delta^{13}C$ patterns are attributed to a decrease in surface productivity which began several thousand years before the C/T boundary event.

Supported by: Swedish Research Council
Grants G-GU4076-112 and G-GU4076-115.

WHOI Contribution No. 5927.

GEOLOGICAL AND GEOPHYSICAL INVESTIGATION
OF THE MID-CAYMAN SPREADING CENTER:
SEISMIC VELOCITY MEASUREMENTS AND
IMPLICATIONS FOR THE CONSTITUTION
OF LAYER 3

J. A. Karson and P. J. Fox

In this paper we present laboratory measurements of compressional and shear wave velocities of a diverse suite of gabbroic rocks collected from the walls of the Mid-Cayman Spreading Center with DSV ALVIN. The degree of deformation and alteration affecting these gabbros is quite variable and there is a correspondingly wide range of laboratory velocities. In fact, the laboratory velocities span most of the range of seismic velocities reported for oceanic and ophiolite rocks, including basalts, gabbros, ultramafics, and their altered derivatives. Based upon these laboratory velocities and the geologic setting of the Mid-Cayman gabbros, it is argued that no unique lithology, except anhydrous peridotite, can be

identified in the oceanic crust and upper mantle from seismic velocity data alone. Furthermore, these data allow for the possibility of considerable lithologic heterogeneity, at the scale of a few centimeters to a few kilometers, that is averaged in seismic refraction studies to give a picture of apparent uniformity.

In press: Geophysical Journal of the
Royal Astronomical Society.

Supported by: NSF Grants EAR80-26445,
OCE83-14951 and OCE76-21882.

WHOI Contribution No. 5910.

NORTH ATLANTIC LATE MIOCENE STABLE
ISOTOPE STRATIGRAPHY, BIOSTRATIGRAPHY
AND MAGNETOSTRATIGRAPHY

L. D. Keigwin, M.-P. Aubry and D. V. Kent

Upper Miocene foraminiferal-nannofossil ooze and chalk at DSDP Hole 552A in the northeast Atlantic Ocean have been closely sampled for biostratigraphic, paleomagnetic and stable isotopic studies. Sampling at 10 cm intervals results in a 1000 to 3000 year resolution in uppermost Miocene isotope stratigraphy.

Covariance in benthic (Planulina wuellerstorfi) and planktonic (Globigerina bulloides) foraminiferal $\delta^{18}O$ records is taken as evidence for variability in continental ice volume. Our best estimate is that glacial maxima occurred at ~5.0 and ~5.5 Ma and lasted no more than 20,000 yrs. These events probably lowered sea level by 60 m below the latest Miocene average. There is little oxygen isotope evidence, however, for a prolonged glaciation during the last 2 m.y. of late Miocene time.

High and low frequency variability in the $\delta^{13}C$ record of foraminifers is useful for correlation among North Atlantic DSDP Sites 408, 410, 522, 610, and 611, and for correlation with sites in other oceans. The same $\delta^{13}C$ changes are seen in P. wuellerstorfi and G. bulloides, but the amplitude of the signal is always greater in G. bulloides. $\delta^{13}C$ variability which is common to both species probably reflects variability in the $\delta^{13}C$ of total CO_2 in seawater. Major long-term features in the $\delta^{13}C$ record include a latest Miocene maximum (P. wuellerstorfi = 1.5‰) in paleomagnetic Chron 7, an abrupt decrease in $\delta^{13}C$ at ~6.2 Ma, and a slight increase at ~5.5 Ma. The decrease in $\delta^{13}C$ at ~6.2 Ma, which has been paleomagnetically dated only twice before, occurs in the younger reversed part of Chron 6 at Holes 552A and

611C, in excellent agreement with earlier studies. Cycles in $\delta^{13}\text{C}$ with a period of ~104 yrs are interpreted as changes in seawater chemistry which may have resulted from orbitally-induced variability in continental biomass.

Samples of *P. wuellerstorfi* younger than 6 Ma throughout the North Atlantic have $\delta^{13}\text{C}$ near 1‰, on average ~1‰ greater than samples of the same age in the Pacific Ocean. Thus, there is no evidence for cessation of North Atlantic Deep Water production resulting from the Messinian "salinity crisis."

Biostratigraphic results indicate continuous sedimentation for the late Miocene younger than ~6.5 Ma at Hole 552A. Nannofossil biostratigraphy is complicated by the scarcity of low-latitude marker species but middle and late Miocene Zones NN7 through NN11 are recognized. A hiatus is evident at ~6.5 Ma, based on the simultaneous first occurrence of *Amaurolithus primus*, *Amaurolithus delicatus*, *Amaurolithus amplificus*, and *Scyphosphaera globulata*. The frequency and duration of older hiatuses increase in Hole 552A as suggested by calcareous nannofossil biostratigraphy and magnetostratigraphy.

Paleomagnetic results at Hole 552A indicate a systematic pattern of inclination changes. Chron 6 is readily identified because of its characteristic nannoflora (sequential occurrences of species assigned to the genus *Amaurolithus*) and the $\delta^{13}\text{C}$ decrease in foraminifers, but its older reversed interval is condensed. Only the older normal interval of Chron 5 is recognized at Hole 552A, the younger normal interval and oldest Gilbert sediment are not recorded due to low intensity of magnetization. Interpreting magnetic reversals older than Chron 6 is difficult because of hiatuses, but an older normally magnetized interval is probably Chron 7.

Correlation between DSDP Hole 552A and other North Atlantic sites is demonstrated using coiling direction changes in the planktonic foraminifer *Neoglobobulimina*. At most sites, this genus changed its coiling preference from dominantly right to dominantly left during late Miocene time. At Hole 552A, this event probably occurred about 7 m.y. ago. At the same time, maximum $\delta^{13}\text{C}$ values were reached in *P. wuellerstorfi*. The same $\delta^{13}\text{C}$ maximum and coiling change co-occurred in Chron 7 at Hole 611C and at Hole 610E. In sediment younger than ~5.5 Ma, the coiling of smaller *Neoglobobulimina* spp. became random but larger *N. atlantica* retained preferential left coiling.

In press: Initial Reports of the Deep Sea Drilling Project, Vol. 94.

Supported by: NSF Grants OCE81-17590 and OCE83-8893.

WHOI Contribution No. 6030.

EARLY MOTION OF THE PLATES AROUND THE NORTHERN ATLANTIC DURING THE LATE JURASSIC-EARLY CRETACEOUS RIFTING

Jacques A. Malod, Kim D. Klitgord and Hans Schouten

Several rifting phases have affected the northern Atlantic area. Some of them have led to a significant stretching of the continental crust and relative motion of the plates on each side of the rift. This was the case during the Late Jurassic-Early Cretaceous around the Bay of Biscay triple junction between North America (Grand Banks), Eurasia (Celtic and Armorican margins) and Iberia (Galicia Bank and North Spanish margins). The kinematic evolution which fits the main fault patterns on these margins includes a late Oxfordian to Hauterivian phase and a Hauterivian to Aptian phase differentiated by a change in the direction of Iberia motion with respect to Eurasia and North America. This study is a qualitative approach to the problem of determining the kinematics between the initial fit of the plates and the oldest relative position given by the plate reconstruction based on sea floor spreading magnetic anomalies. Improvement of the model depends largely on a better knowledge of the age and structural pattern of the rifting phases.

In press: Marine Geology.

Supported by: A U.S./French exchange grant to J.A. Malod and NSF Grant OCE83-09027.

WHOI Contribution No. 6012.

DEEP CURRENT-CONTROLLED SEDIMENTATION IN THE WESTERN NORTH ATLANTIC

I. N. McCave and Brian E. Tucholke

With its multiple sources of sediment and bottom water, the North Atlantic experiences more active redistribution of sediments than most other ocean basins. North Atlantic bottom waters originate around Antarctica, in the Norwegian Sea, the Mediterranean, and the Labrador Sea. Sediment is supplied from continental land-masses, oceanic islands (notably Iceland) and from surface biological production. The water movements are controlled principally by differing densities of the water masses,

and the currents tend to follow the contours of the sea floor. Where interfaces of steep density gradient intersect the seafloor, internal tides and high-frequency internal waves may also resuspend sediments. The Gulf Stream, and warm-core and cold-core mesoscale eddies with clockwise (anti-cyclonic) and anticlockwise (cyclonic) circulation, apparently contribute to the variability of current velocity at great depths and help to erode and redistribute sediments.

The most important depositional products of this current activity are the great "sediment drifts" of the region. These features probably contain a detailed but as yet poorly known record of the fluctuations in bottom-current activity of the North Atlantic. They have formed principally since the beginning of the Oligocene, when strong abyssal circulation began in the North Atlantic (Hollister and Ewing, 1972; Tucholke and Mountain, 1979; Miller and Tucholke, 1983). The precise relationship of the drifts to the present abyssal current regime is not clear because details of that regime are poorly known. Few long-term, deep current-meter records have been taken and most of these are not adjacent to drifts. The drifts are mantled by smaller-scale bedforms including mud waves, furrows, longitudinal and transverse ripples, biogenic mud-mounds with depositional tails, and smaller current-produced lineations. The drifts and their bedforms constitute the result of what we earlier termed "plastering and decorating" on the sides of the North Atlantic ocean basin (Hollister and others, 1978). We give a summary account of this decorative distribution of material and its control by the deep circulation.

In press: "The Geology of North America: The Western Atlantic Region".
P. R. Vogt and B. E. Tucholke, eds.
Geological Society of America.

Supported by: ONR Contract N00014-82-C-0019.

WHOI Contribution No. 5970.

GEOLOGY OF THE GULF OF THE PERSIAN GULF: GULF OF OMAN REGION: A SYNTHESIS

David A. Ross, Elazar Uchupi
and Robert S. White

The Persian Gulf is a remnant of a former platform (the Arabian platform) that during the Mesozoic formed most of the Arabian Peninsula, the Gulf, and southwestern Iran. Collision of the Arabian platform (part of the African plate at that

time) and the Eurasian plate along the Zagros Crush zone beginning in the Turonian, and compressional deformation of the Musandam Peninsula during the Turonian to lower Maestrichtian and mid-Tertiary diminished the area of the platform. Uplift of the Oman Mountains and subsidence of the Musandam Peninsula since the Miocene, formation of the Zagros Mountains during Plio-Pleistocene, and a 600-400 m drop in sea level since the Cretaceous has reduced the platform to the Persian Gulf. Plastic flow of salt, fluvial erosion during late Pleistocene, and vertical neotectonics in the Holocene are other factors that have influenced the area's present morphology.

In press: Review of Geophysics.

Supported by: NSF Grant OCE76-10417;
NOAA Sea Grant NA-83-AA-D-00049
(M/O-1); and an Iranian grant.

WHOI Contribution No. 5879.

SEISMIC STRATIGRAPHIC CORRELATION ACROSS THE NEW ENGLAND SEAMOUNTS, WESTERN NORTH ATLANTIC

Stephen A. Swift, Cynthia J. Ebinger
and Brian E. Tucholke

Correlation in the western North Atlantic Basin of deep-water seismic stratigraphy across a basement high within the New England Seamounts shows that the seismic sequence of the Nova Scotian rise is broadly similar to that off the United States. Age of seamount volcanism inferred from stratigraphic relations around the basement high is consistent with a hot-spot origin, but nearby stratigraphic data indicate earlier and later eruptions occurred, suggesting lithospheric weakness that predisposed this area to volcanism. Patterns of Tertiary abyssal current erosion and sediment deposition were controlled by seafloor morphology around the seamounts and interaction of abyssal currents with the Gulf Stream.

In press: Geology.

Supported by: NSF Grant OCE81-18014.

WHOI Contribution No. 6013.

STRUCTURE OF BASEMENT AND DISTRIBUTION OF SEDIMENTS IN THE WESTERN NORTH ATLANTIC

Brian E. Tucholke

During the past 20 years the morphology of the seafloor has become relatively well

known along the crest and shallow flanks of the Mid-Atlantic Ridge through echo sounding and seismic reflection profiling. In this area, sediment cover is so thin, rarely more than 50-100 m, that high frequency echo sounding (12 kHz) essentially maps the surface morphology of oceanic crust. Although our knowledge of this crustal morphology still is far from being detailed or complete, the observed patterns and spacing of fracture zones and crustal blocks provide a general model that can be used to understand the basement morphology in more thickly sedimented regions away from the ridge crest. Structure contours on basement for most of the western North Atlantic recently have been compiled by Tucholke and others (1982) and Tucholke and Fry (1985). Their mapping used the crustal "template" of the mid-ocean ridge together with data from all available seismic reflection profiles in the western Atlantic basins. With some additional mapping, I have extended these structure contours to cover the area from the Mid-Atlantic Ridge crest west to the continental margin between about 13°N and 70°N.

Until the basement morphology is completely masked by sediments, it exerts strong control on how sediments are distributed in the ocean basin. Gravity-controlled mass movements such as debris flows and turbidity currents deposit their sediment load in the deepest accessible basins; consequently, thick ponded sediments often are observed in fracture-zone troughs. Basement peaks and ridges also can influence the path and intensity of deep currents and thereby cause differential deposition over distances of a few kilometers to hundreds of kilometers (McCave and Tucholke, this volume; see Profiles J,L). Thus, once the morphology of the basement is understood, it becomes possible to map sediment thickness in a meaningful way and to study more effectively the geologic processes that control sediment distribution.

In press: "The Geology of North America: The Western Atlantic Region". P. R. Vogt and B. E. Tucholke, eds. Geological Society of America.

Supported by: ONR Contracts N00014-79-C-0071 and N0014-82-C-0019 and a Mellon Senior Study Award.

WHOI Contribution No. 5972.

BASEMENT STRUCTURE AND SEDIMENT DISTRIBUTION IN THE NORTHWEST ATLANTIC OCEAN

Brian E. Tucholke and Virginia A. Fry

We have interpreted all available single-channel and multichannel seismic reflection profiles and integrated these data with existing charts to produce maps of structure contours on basement and isopachs of sediment thickness in the northwestern Atlantic Ocean, including the Labrador and Irminger basins. Contours are in meters, derived by applying velocity-regression equations based on sonobuoy results; this gives a more accurate representation of geologic relations than is possible in reflection-time mapping. Major structural relations and sediment distribution for the Mid-Atlantic Ridge, Mid-Labrador Sea Ridge, Davis Strait, and adjacent Greenland and eastern Canadian continental margins are clearly defined in the maps. We discuss the principal basement features within the context of the plate-tectonic evolution of the region and review controls on the development of the sedimentary provinces through time.

Published in: American Association of Petroleum Geologists Bulletin, 69, 2077-2097 and AAPG Map Series.

Supported by: ONR Contracts N00014-79-C-0071 and N00014-82-C-0019.

WHOI Contribution No. 5915.

PALEOGEOGRAPHIC AND PALEOBATHYMETRIC EVOLUTION OF THE NORTH ATLANTIC OCEAN

Brian E. Tucholke and Floyd W. McCoy

The principles of plate tectonics that have been developed over the past 25 years provide a conceptual and predictive framework that allows relatively detailed reconstruction of the geologic history of ocean basins. Excluding extra-terrestrial effects, tectonics of the earth's crust is the primary mechanism that controls the evolution of the geologic record. Secondary mechanisms that are related to tectonics through direct or indirect pathways create complicating and less easily predicted signals in the oceanic sedimentary record. In this paper, we use plate-tectonic concepts to reconstruct the morphology and geologic conditions of the North Atlantic Ocean basin in twelve time slices from the Late Triassic (Atlantic closures) to the present. The specific time slices selected represent a balance between depiction of major tectonic/oceanographic "events" and

portrayal of important, longer-term geologic episodes of, for instance, relatively stable circulation and depositional patterns. Within each time-slice we have superimposed the major tectonic patterns, seamounts, oceanic circulation, and sedimentary lithofacies. While we have made this compilation as complete and coherent as possible within the time available, we point out that the synthesis is still a limited effort compared to the vast literature that exists on the geology of the North Atlantic. Furthermore, we have made the compilations at a small scale, so many generalizations are necessary. Despite such deficiencies, these "first-generation" maps provide a good summary of our present knowledge of the geologic conditions in each time-slice.

Although this volume of *The Geology of North America* in the strict sense deals only with the western North Atlantic, we have dealt with the entire North Atlantic basin and its marginal seas. From the time that the North Atlantic first began to have a "basinal" character in the Late Triassic, the western Atlantic region was affected by external environmental conditions that with time were increasingly more global in extent. Accordingly, we present an overview of North Atlantic evolution as a reasonable compromise between purely regional (western North Atlantic) and global viewpoints.

In press: "The Geology of North America: The Western Atlantic Region". P. R. Vogt and B. E. Tucholke, eds. Geological Society of America.

Supported by: ONR Contracts N00014-79-C-0071 and N00014-82-C-0019; NSF Grant OCE70-09382; and a Mellon Senior Study Award.

WHOI Contribution No. 5980.

THE CHARACTERISTICS OF THE CHINA COASTLINE

Ying Wang and David G. Aubrey

Evolution of China's coastline reflects the influence of geology, rivers, climate, typhoons, waves, tides, shelf currents, and sea-level changes. While tectonics control the broad-scale appearance of the coast (either bedrock-embayed in emergent regions or plains coast in subsiding regions), rivers dominate the supply of sediment to the shore and help control erosional/accretionary trends. The Yellow River (Huang He) is the world's largest in terms of sediment supply, while the Yangtze River (Chang Jiang) is the fourth largest in

terms of water discharge. The size of these large rivers, combined with their instability over recent geological and historical times, accentuates their impact on coastal development in China. Since the migration of the Yellow River northwards from the Yellow Sea into the Bohai Sea in 1855, the north Jiangsu coast has eroded approximately 17 km inland, while the new delta near Lijin has encroached about 28 km into the Bohai Sea.

The coastal classification of Wang (1980) is applied to the coast of China, dividing China into four major sectors. Relative impact of rivers, waves and tides on coastal processes in each of these sectors varies widely, ranging from river-dominated in the Bohai Sea sector, to wave-dominated in the southern Guangdong/Guanxi sector. This classification and discussion summarizes major studies of coastal processes in China; such a summary has not been previously available to the western world.

In press: Continental Shelf Research.

Supported by: NOAA Sea Grant NA83-AA-D-00049 and the Coastal Research Center, WHOI.

WHOI Contribution No. 6026.

G E O P H Y S I C S

GRAVITY AND GEOID ANOMALIES OF THE CARIBBEAN REGION: A PROGRESS REPORT

Carl Bowin

Gravity and geoid anomalies are indicators of mass anomalies and as such can be used to aid determination of lithospheric structure and degree of vertical tectonic activity. Published contour maps of gravity and geoid anomalies show patterns of their variations but are not adequate for numerical processing. To overcome that handicap we are presently creating a digital data base of gridded gravity and geoid anomalies for the world. From the gridded data base, contour maps can be readily constructed; we show our initial test results for the Caribbean region from a combination of surface gravity and SEASAT radar altimeter data. In principal, gravity and geoid are equivalent descriptors of the earth's potential field in that one can be transformed to the other via a radial derivative or integral. However, because portions of the earth lack either gravity or geoid observations, and existing measurements have errors, the study of fea-

tures with dimensions from roughly 50 km to 500 km wavelength can benefit from combined analysis of both data sets. Simple ratios of single observations of different data types (e.g., geoid, gravity, or gravity gradient) at the centers of anomaly features provide information comparable to the traditional spatial and frequency analyses of one data type alone. By assumption of the anomalous mass geometry, the ratios can readily provide initial estimates of depth of anomalous mass. We discuss both gravity and geoid anomalies and their residuals. Residual gravity and geoid anomaly maps show the remaining fields after the long wavelength contributions from mass anomalies in the lower mantle and at the core/mantle boundary have been subtracted from the observed fields. These data are used to illustrate the effectiveness of considering both gravity and geoid data in interpreting structure and tectonics.

In press: Transactions of the First Geological Conference of the Geological Society of Trinidad and Tobago. Fourth Working Symposium on Oceanographic Data Systems, 1986.

Supported by ONR Contract N00014-B2-C-00019 and NASA Grant NAG5-593.

WHOI Contribution No. 5999.

GEOPHYSICAL DATA BASE AND PROCESSING SYSTEM

Carl Bowin and Julie Allen

Storage, access, processing, and display of the large quantities of data presently available are fundamental problems for the scientific researcher. Until 1985, the problem of obtaining thousands of computing hours on a fast processor, at a cost we could afford, seemed insurmountable. We now have a geophysical database management and processing system operational in our laboratory under normal air conditioning. By early 1986, we anticipate having storage of gigabytes of digital data with on-line access, and unlimited processing capability at speeds faster than a VAX 11/780. Several display options are also provided.

In press: IEEE Computer Society Press.

Supported by: ONR Contract N00014-85-C-0001.

WHOI Contribution No. 6075.

MASS ANOMALIES FROM COMBINED INVERSIONS OF GRAVITY, GEOID, AND GRAVITY GRADIENT ANOMALIES

Carl Bowin, Edward Scheer
and Woolcott Smith

The utility of combining geoid, gravity, and vertical gravity gradient measurements for the delineation of causative mass anomalies is explained and compared with spatial and spectral methods for depth estimation. Depth rules for various source geometries are reviewed and new rules developed for geoid data. Both spatial and frequency domain methods are discussed. Simple ratios of single observations of different data types (eg. geoid, gravity, or gravity gradient) are shown to provide information comparable to the traditional spatial and frequency analyses of one data type alone.

In press: Geophysics.

Supported by: ONR Contract N00014-82-C-0019.

WHOI Contribution No. 5684.

A COMPARISON OF HIGH-RESOLUTION SEISMIC METHODS FOR DETERMINING SEABED VELOCITIES IN SHALLOW WATER

T. M. Brocher and J. I. Ewing

The ability to resolve both the seismic velocity of the seabed in shallow water and the lateral variability of these measured velocities using four conventional seismic methods are compared. The four methods described here differ in the ease and efficiency in which the field data are collected, interpreted, and in the resolution of the velocity of the seabed they provide. Narrow-aperture refraction studies provide limited constraints due to the frequent absence of first-arriving sediment refractions in the narrow portion of the wavefield that is sampled. Wide-aperture refraction experiments using ocean bottom seismometers provide high-resolution of both the compressional- and shear-wave velocities of the seabed but are time-consuming to perform and to interpret. Narrow-aperture multichannel reflection data are easily collected, and are ideal for areal mapping of sedimentary sequences, but resolution of seismic velocities is low unless the aperture of the multichannel streamer is several water depths in length. Wide-aperture multichannel reflection profiling generally provides the highest resolution in velocity in all geoaoustic environments, including those which pro-

duce little or no pre-critical reflected energy and little dispersion of the acoustic normal modes. Moreover, difference seismic wavefields calculated by subtracting a reference seismic wavefield from adjacent wavefields provides an objective means of rapidly mapping the lateral variability of the seabed.

In press: Journal of the Acoustical Society of America.

Supported by: ONR Contract N00014-82-C-0019.

WHOI Contribution No. 5937.

INNER CORE EXPERIMENTS: TELESEISMIC EXPLORATION OF THE ANTIPODE

Rhett Butler, Thomas M. Brocher,
Jose A. Rial and Charles F. Richter

A seismic experiment at the antipode of a nuclear test will yield high resolution data for the inner core, outer core, and core-mantle boundary of the earth which is not obtainable at any other place on the earth's surface. The antipode to the Nevada test site lies 180° opposite in the Crozet Basin of the Southwest Indian Ocean between Madagascar and Kerguelen. An ocean bottom seismometer (OBH) array deployment at the antipode is feasible with present day navigation and technology. Current seismic wave propagation techniques can handle the analysis and modeling of data from an antipode experiment. The primary impediments of an antipode experiment are threefold: (1) security of nuclear tests, (2) ship scheduling and (3) funding coordination. Although difficulties are presented by each, the obstructions can be overcome.

In press: EOS, Transactions of the American Geophysical Union.

Supported by: NSF Grant OCE84-01649.

WHOI Contribution No. 5904.

CONTROLLED SOURCE ELECTROMAGNETIC SOUNDING OF THE OCEANIC LITHOSPHERE

C. S. Cox, S. C. Constable, A. D. Chave
and S. C. Webb

A dipole-dipole electromagnetic sounding was carried out in the north Pacific during 1984 on crust of 25 m.y. age (magnetic anomaly 6E) having thin sediment cover. The technique was similar to that used in earlier work. Electromagnetic

signals in the frequency range of 0.06 to 24 Hz were injected into the ocean and seabed by a horizontal electric dipole antenna dragged along the seafloor by a surface ship. The electric fields that propagated through the resistive basement were detected by receivers at ranges of 10 to 65 km. Ionospheric signals in this frequency band are greatly attenuated by the seawater, which precludes the use of the magnetotelluric method for studying the oceanic lithosphere. In fact, the ambient seafloor electric field is very small, varying from 10^{18} (V/m)²Hz⁻¹ at 0.1 Hz to 10^{-24} (V/m)²Hz⁻¹ above 1 Hz, allowing the very small controlled source signals to be measured. The data are consistent with a simple, one-dimensional earth model consisting of a 3-7 km thick crustal layer of moderate conductivity (~.001 S/m) underlain by a thicker region of very low conductivity ($<2 \times 10^{-5}$ S/m). The conductivity of the upper mantle is most important for the interpretation of seafloor magnetotellurics, motional electromagnetic fields, water content, petrology, and thermal structure of the lithosphere. For example, the results presented here suggest that the upper mantle contains at most 0.1% water by volume.

In press: Nature.

Supported by: NORDA Contract N00014-83-K-0546.

WHOI Contribution No. 6049.

THERMAL AND MECHANICAL CONSTRAINTS ON THE LITHOSPHERE BENEATH THE MARQUESAS SWELL

Karen M. Fischer, Marcia K. McNutt
and Loren Shure

The Marquesas Islands cap a broad swell of presumably thermal origin. We apply a linear filtering technique to geoid height and depth anomaly data over the Marquesas to determine the depth to the low-density material responsible for elevating the swell. Our method does not assume the separation of the swell and the islands in either the spatial or the spectral domain and does not require initial estimates of swell height or width. We determine a compensation depth of 45 ± 5 km for the swell and best fitting values for lithospheric flexural rigidity and island load density of 5×10^{22} Nm and 2700 kg/m^3 , respectively. The shallow compensation depth and low flexural rigidity call for elevated temperatures within the lithosphere.

Supported by: NSF Grant OCE84-09157
and ONR Contract N00014-82-C-0019.

WHOI Contribution No. 6089.

THE SPREADING RATE DEPENDENCE OF OCEANIC SEISMIC LAYER 2

L. Kong, T. M. Brocher and R. A. Stephen

Comparison of travel-time and amplitude data from two Oblique Seismic Experiments located on 110 m.y. old oceanic crust in the western Atlantic and northwestern Pacific Oceans show that compressional velocities within layer 2 are, within experimental error, identical at the two sites. This result implies that, at least for 110 m.y. old crust, the velocity structure in layer 2, where extrusive lavas grade downward into a sheeted dike complex, is independent of the spreading rate at which the crust was created.

Published in: Geophysical Research
Letters, 12, 219-222.

Supported by: NSF Grants OCE83-01649
and OCE84-09155.

WHOI Contribution No. 5905.

THERMAL CONDUCTIVITY VARIATION IN A DEEP-SEA SEDIMENT CORE AND ITS RELATION TO H₂O, Ca AND Si CONTENT

Jun-Ichi Matsuda and R.P. Von Herzen

A total of 146 thermal conductivity values were determined on a single deep-sea sediment core of about 9m length taken in the eastern equatorial Pacific (1°02.2'N, 121°10.4'W). The variation of thermal conductivity values ranges from 1.5 to 2.5 mcal/cm sec° C. and has no simple relation to the depth below the sea floor. The relative proportions of H₂O, CaCO₃, and SiO₂ were also determined on a dozen samples of this sediment core, showing a good negative correlation of CaCO₃ and positive correlation of SiO₂ with H₂O contents. These correlations reflect the differences in grain size distributions and/or in skeletal shapes of calcareous and siliceous microfossils in the deep-sea sediment. The relationship of thermal conductivity to these other physical variables is discussed.

In press: Deep-Sea Research.

Supported by: NSF Grant OCE77-28281.

WHOI Contribution No. 5848.

ESTIMATING THE COMPENSATION DEPTH OF THE HAWAIIAN SWELL WITH LINEAR FILTERS

Marcia McNutt and Loren Shure

Broad areas of anomalously shallow sea-floor surround regions of active or recently active hot spot volcanism. The cause of these midplate swells has been modeled both as convectively-maintained elevated temperatures in the underlying asthenosphere and as thermal expansion within the lithosphere itself. According to the former explanation, we would expect the low-density material compensating the swell to lie within the asthenosphere, whereas the latter model predicts compensation at lithospheric depths. We present a technique based on the application of linear filters for determining the compensation depth of midplate swells given observations of topography and geoid or gravity anomalies. Our method does not require an a priori estimate of swell height or width nor does it assume spatial or spectral separation between the swell topography and the signal from the hot spot volcanoes, which are compensated by flexure of the oceanic Moho. Rather, we exploit the difference in the predicted sign and amplitude of the Moho deflection beneath elevated topography produced by loading above versus loading below the elastic plate in order to separate the two effects. An application of these linear filters to residual topography and geoid data from the region surrounding the Hawaiian hot spot yields a compensation depth of 70 ± 10 km, within the lower lithosphere.

Supported by: ONR Contract N00014-82-C-0019.

WHOI Contribution No. 6048.

THE CRUSTAL STRUCTURE OF THE MID-ATLANTIC RIDGE AT 23°N FROM SEISMIC REFRACTION STUDIES

G. M. Purdy and Robert S. Detrick

An explosive seismic refraction experiment using four ocean bottom hydrophone receivers was carried out along a 120 km long section of the Mid-Atlantic Ridge (MAR) median valley at latitude 23°N immediately south of its intersection with the Kane Fracture Zone. The data are interpreted in terms of laterally homogeneous, horizontally layered structures using travel time inversion and synthetic seismogram modelling techniques. These solutions are combined using two-dimensional ray tracing to produce a single model defining the major along-axis structural

changes occurring beneath this section of the median valley. With the exception of slightly low Layer 3 velocities, the crust beneath several tens of kilometers of the MAR median valley has all the characteristics of simple, mature ocean crust, including a well-defined Moho transition zone, ~8 km/s upper mantle velocities, and a total crustal thickness of 6-7 km. No evidence is found for the presence of a steady state axial magma chamber in the crust or upper mantle and the excellent propagation characteristics and orderly amplitude versus range relationships imply the existence of a considerable degree of lateral homogeneity beneath the median valley over distances of several tens of kilometers along-axis. We infer from these observations that the basic seismic characteristics of the ocean crust are "frozen-in" in a time period less than that separating the major volcanic injection events (10,000-50,000 years) by hydrothermal circulation penetrating to the base of the crust. Along the 100 km long ridge segment studied here, two major along-axis structural changes occur. The first is a 10-15 km wide (along-axis) zone of lowered velocities in the lower crust centered beneath a major along-axis topographic high. This is interpreted to be the remnants of the most recent phase of injection that has temporarily left behind it a region of elevated temperatures and pervasive cracking and thus reduced velocities. The second occurs abruptly at latitude 23°15'N and is accompanied by both a major change in rift valley and crestal mountain morphology and the apparent non-coincidence of the median valley and central magnetic anomaly. North of this boundary, the ~30 km long ridge segment that abuts the Kane Fracture Zone has a crustal thickness of 4-5 km and no distinctive layering to produce the characteristic amplitude patterns that typify mature oceanic crust. Interpretation of the cause of this structural change is uncertain but may be related to local tectonic events, perhaps a recent 10-20 km ridge jump to the east.

In press: Journal of Geophysical Research.

Supported by: NSF Grant OCE80-25206.

WHOI Contribution No. 5918.

THE ACCURACY OF MODELS DERIVED BY WKBJ WAVEFORM INVERSION

Peter R. Shaw

In this paper we quantitatively evaluate the accuracy of velocity-depth profiles

derived by matching WKBJ seismograms to observations. Seismograms computed with the WKBJ method are generally quite reliable but possess predictable, systematic inaccuracies in the presence of strong velocity gradients. The effects of these inaccuracies on models derived through WKBJ waveform inversion are studied, using reflectivity seismograms as "data." The velocity structure used is an oceanic lithosphere model that contains several transition regions separated by relatively homogeneous layers, producing partially-reflected reverberations in the reflectivity synthetics that are absent from the WKBJ seismograms. The inversion incorporates the "jumping" strategy to solve for the smoothest models consistent with the data. These solutions are independent of the starting model and have a stable basic structure that agrees well with the correct model. The differences, everywhere less than a seismic wavelength, depend on the frequency content of the seismograms. Reverberations in the reflectivity seismograms that are well separated from WKBJ arrivals are treated as "noise" in the inversion.

In press: Geophysical Journal of the Royal Astronomical Society.

Supported by: ONR Contracts N3014-82-C-0019 and N3014-85-C-0001.

WHOI Contribution No. 5981.

SEISMIC ANISOTROPY IN THE UPPER OCEANIC CRUST

R. A. Stephen

Seismic anisotropy in the upper oceanic crust is observed in borehole data obtained at Deep Sea Drilling Project (DSDP) Site 504B on DSDP Leg 92. Particle motion analysis of converted shear wave arrivals from explosive sources at various azimuths reveals a set of patterns which is indicative of hexagonally isotropic structure with a horizontal symmetry axis.

There are four diagnostic patterns: 1) along symmetry axes, where vertically polarized shear waves (SV) are generated but horizontally polarized shear waves (SH) are not generated; the particle motions are purely vertical; 2) azimuths at which both SV and SH are generated and the SH velocity is significantly faster than SV; a cruciform pattern with horizontal first motion is observed; 3) azimuths at which both are generated and the SV velocity is significantly faster than SH; a cruciform pattern with vertical first motion is observed; and 4) azimuths at which both are generated and SV and SH

velocities are similar; elliptical particle motions are observed.

The shear wave particle motions and compressional wave travel times (from a 2 km radius circle) are consistent with an anisotropic model with hexagonal symmetry. The compressional wave velocity has a two theta variation between 4.0 and 4.8 km/sec. The symmetry axis is horizontal with an azimuth of $N20^{\circ}W \pm 10^{\circ}$. The spreading direction at the site (6 my age) is north-south.

The observed seismic anisotropy is most probably caused by the preferred orientation of large scale fractures and fissures in upper layer 2 which were created in the early stages of crustal development by near axis extensional processes and normal block faulting.

Published in: Journal of Geophysical Research, 90, 11,383-11,396.

Supported by: NSF Grants OCE81-17571 and OCE81-09155.

WHOI Contribution No. 5942.

A MULTICHANNEL SEISMIC STUDY OF
LITHOSPHERIC FLEXURE ACROSS THE
HAWAIIAN-EMPEROR SEAMOUNT CHAIN

A. B. Watts, U. S. ten Brink,
P. Buhl and T. M. Brocher

Existing models assume that the thickened crust beneath seamounts is the result of a surface volcanic load flexing an elastic plate. New results obtained using the two-ship multi-channel seismic technique have revealed information on the detailed velocity and crustal structure of the Hawaiian-Emperor seamount chain. These results suggest that flexed oceanic crust beneath the chain is underlain by a 4 km thick deep crustal body. We interpret the body as a deep crustal sill complex associated with the tholeiitic stage of volcano building along the chain.

Published in: Nature, 315, 105-111.

Supported by: NSF Grants OCE81-17210 and OCE84-43349.

WHOI Contribution No. 5710.

COHERENT PRESSURE FLUCTUATIONS OBSERVED
AT TWO SITES ON THE DEEP SEA FLOOR

Spahr C. Webb

Pressure fluctuations from two sites on the deep sea floor separated by a dis-

tance of 32 km were found to be partially coherent at frequencies between .001 Hz and .015 Hz. The pressure fluctuations in this range are caused by surface gravity waves which are of sufficiently long wavelength that significant coherence exists. No coherence is detected at lower frequencies because temperature fluctuations disturb the reference in the pressure gauge, while at higher frequencies the surface gravity wave induced pressure fluctuations are sharply attenuated through the ocean. The real part of the coherency as a function of frequency resembles a J₀ Bessel function of argument kr (r is the distance between the sites and k is the magnitude of the wavenumber as determined by the surface gravity wave dispersion relation). The imaginary part of the complex coherency is smaller than the real part over most of the surface gravity wave band. The coherency is well modeled if the surface gravity wave field is assumed to be isotropic, but other models for the directional spectrum which require a very broad distribution in direction of propagation fit equally well. Narrow beam width models fit the data poorly.

In press: Geophysical Research Letters.

Supported by: ONR Contract N00014-83-K-0546.

WHOI Contribution No. 6078.

MICROSEISM PROPAGATION BETWEEN
TWO SITES ON THE DEEP SEA FLOOR

Spahr C. Webb and Steven C. Constable

Pressure and electric field fluctuations detected at two sites separated by a distance of 32 km on the deep sea floor are found to be partially coherent at frequencies between .05 and .6 Hz. The phase relationships observed between the two sites suggest coherent wave trains from three source regions produce the observed coherence. Plausible estimates for the azimuths to the sources can be obtained if Rayleigh wave phase velocities are assumed. Each source region is associated with a different peak in the power spectra of the pressure and electric field fluctuations. One source region is along the California coastline where microseisms between .05 and .1 Hz are generated by the steepening and breaking of swell along that coast. The two other source regions are in deep water where microseisms are produced by nonlinear interaction of surface gravity waves. These microseisms have frequencies which are double the frequency of principal

surface gravity wave components. A region to the southeast of the two sites is associated with microseisms near .16 Hz, and a region to the northwest is associated with microseisms near .25 Hz.

Supported by: NORDA Contract N00014-83-K-0546.

WHOI Contribution No. 6086.

P A L E O C E A N O G R A P H Y

COMPARISON OF ATLANTIC AND PACIFIC PALEOCHEMICAL RECORDS FOR THE LAST 215,000 YRS: CHANGES IN DEEP OCEAN CIRCULATION AND CHEMICAL INVENTORIES

E. A. Boyle and L. D. Keigwin

Detailed Cd/Ca and $\delta^{13}\text{C}$ data have been obtained for benthic foraminifera from Western North Atlantic and Equatorial Pacific sediment cores. In the modern ocean, both tracers are closely linked to nutrient distributions. The sedimentary records for both tracers indicate that bottom waters overlying the Atlantic site have been nutrient-depleted relative to those at the Pacific site over the last 215,000 years. From this evidence it is reasonable to infer that there has been a continuous net flux of nutrient-depleted water from the Western North Atlantic into the Pacific. This exchange has undergone significant fluctuations, with the export of nutrient-depleted Atlantic water diminishing by about a factor of two relative to the inflow from Southern Ocean sources. Over the last 215,000 years, carbon isotope fluctuations in both regions are dominated by variable storage of isotopically light carbon on continents with a lesser contribution from these deep ocean circulation changes. The cadmium signal in the North Atlantic is dominated by changes in deep ocean circulation patterns; cadmium shows less variability in the Pacific which may reflect changes in the global average cadmium content or minor changes in deep Pacific circulation patterns. Using these records to estimate global averages, it appears that glacial ocean water had 22% more Cd and 0.46 per mil less ^{13}C than the modern ocean. These numbers are estimates which may be revised as more data becomes available, although they are not likely to be as much as 20% in error for Cd or 0.2 per mil for ^{13}C . Relative North Atlantic Deep Water (NADW) formation rates are modulated with a significant 41 kyr periodicity linked to

obliquity-induced variations in high latitude insolation; NADW lags 8 ± 2 kyr behind insolation, however.

In press: Earth and Planetary Sciences Letters.

Supported by: NSF Grant OCE82-17644.

WHOI Contribution No. 6025.

MIDDLE PLIOCENE CHANGE IN PLANKTONIC FORAMINIFERAL FAUNA AT SITE 606

Lisa M. Ehrmann and Lloyd D. Keigwin

A "total fauna" curve (Ruddiman, 1971) shows that surface water overlying DSDP Site 606 (Central North Atlantic Ocean) cooled suddenly at 3.1 Ma within the Mammoth paleomagnetic reversed interval. At that time G. puncticulata, N. pachyderma, and G. crassaformis increased and G. hirsuta, G. Sacculifer, and Sphaeroidinellopsis decreased in abundance. Oxygen isotope results on G. bulloides do not indicate a "stepwise" cooling but probably reflect small changes in continental ice volume. It is proposed that as annual average temperatures decreased, production of G. bulloides was delayed to follow a preferred temperature habitat.

In press: Initial Reports of the Deep Sea Drilling Project, Vol. 94.

Supported by: NSF Grant OCE83-08893.

WHOI Contribution No. 5909.

PLIOCENE STABLE ISOTOPE RECORD OF DSDP SITE 606: SEQUENTIAL EVENTS OF ^{18}O ENRICHMENT BEGINNING AT 3.1 MA

L. D. Keigwin, Jr.

Stable isotope analysis of two species of benthic foraminifera (P. wuellerstorfi and G. subglobosa) and one planktonic species (G. bulloides) from DSDP Site 606 reveal the evolution of late Pliocene climate change. No "stepwise" increase is evident in the $\delta^{18}\text{O}$ record at 3.2 Ma, but events of ^{18}O -enrichment occurred in increasing magnitude at 3.1, 2.7, 2.6, and 2.4 Ma. The younger two events are correlated with events at northeast Atlantic DSDP Hole 552A, indicating glaciation (Shackleton *et al.*, 1984). The oldest spike, centered within the Mammoth Paleomagnetic Event, is the most prominent feature of results between 3 and 4 Ma in age. This isotope event is interpreted as evidence of 2°C bottom-water cooling

combined with minor glaciation.

Carbon isotope results on P. wuellerstorfi indicate Site 606 has been under the influence of North Atlantic Deep Water for most of the interval 2-4 Ma. A significant change in "vital effect" on G. subglobosa at 2.4 Ma is evident in the $\delta^{13}\text{C}$ record. Specimens at that time become smaller and less abundant than older specimens and have ^{13}C values lowered by as much as 1‰. This effect could introduce a significant artifact into data sets where various species are "corrected" to P. wuellerstorfi.

In press: Initial Reports of the Deep Sea Drilling Project, Vol. 94.

Supported by: NSF Grant OCE83-08893.

WHOI Contribution No. 6031.

STABLE ISOTOPES IN LATE MIDDLE EOCENE TO OLIGOCENE FORAMINIFERA

Lloyd D. Keigwin and Bruce H. Corliss

Oxygen and carbon isotope ratios in Eocene and Oligocene planktonic and benthic foraminifera have been investigated from Atlantic, Indian, and Pacific Ocean locations. The major changes in Eocene-Oligocene benthic foraminiferal oxygen isotopes were enrichment of up to 1‰ in ^{18}O associated with the middle/late Eocene boundary and the Eocene/Oligocene boundary at locations which range from 1 to 4 km paleodepth. The synchronous Eocene-Oligocene enrichment began in the latest Eocene, but most of the change occurred in the earliest Oligocene. The earliest Oligocene enrichment in ^{18}O is always larger in benthic foraminifera than in surface-dwelling planktonic foraminifera, suggesting a combination of deep-water cooling and increased ice volume. Planktonic foraminiferal $\delta^{18}\text{O}$ does not increase across the middle/late Eocene boundary at our one site with the most complete record (DSDP 363, Walvis Ridge). This pattern suggests that benthic foraminiferal $\delta^{18}\text{O}$ increased 40 million years ago because of increased density of deep waters, probably due to cooling, although glaciation cannot be ruled out without more data.

Stable isotope data are averaged for late Eocene and earliest Oligocene time intervals to evaluate paleoceanographic change. Average $\delta^{18}\text{O}$ of benthic foraminifera increased by 0.64‰ from the late Eocene to the early Oligocene $\delta^{18}\text{O}$ maximum, whereas for planktonic foraminifera the average increase was 0.52‰. This similarity suggests that the Eocene/Oligocene boundary $\delta^{18}\text{O}$ increase was

caused primarily by increased continental glaciation, coupled with deep sea cooling by as much as 2°C at some sites. Average $\delta^{18}\text{O}$ of surface-dwelling planktonic foraminifera from 14 upper Eocene and 17 lower Oligocene locations, when plotted versus paleo-latitude, reveals no change in the latitudinal $\delta^{18}\text{O}$ gradient. The Oligocene data set is offset by ~0.45‰, also believed to reflect increased continental glaciation. At present, there are too few deep sea sequences from high latitude locations to resolve an increase in the oceanic temperature gradient from Eocene to Oligocene time using oxygen isotopes.

In press: Geological Society of America Bulletin.

Supported by: NSF Grant OCE80-08879.

WHOI Contribution No. 6015.

LATE QUATERNARY STABLE ISOTOPE PALEOCEANOGRAPHY OFF SOUTHERN CALIFORNIA

Gao Liang, K. O. Emery and L. D. Keigwin

Nearly 1000 $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ analyses were made on foraminifera from 16 piston cores in silled basins off southern California. Radiocarbon and faunal dates in the cores allow the isotope ratios to be plotted in map form for the following times: present, 5,000 yr. B.P., 10,000 yr. B.P., 15,000 yr. B.P., and to some extent 20,000 yr. B.P. These maps reveal consistent flow paths of bottom water into the basins, but areas of upwelling shifted to northern basins during interglacial times. Differences between the $\delta^{18}\text{O}$ -depth curves for the different times indicate maximum $\delta^{18}\text{O}$ at 15,000 yr. B.P. due to increased volume of continental ice, but changes in the shape of the curves are insignificant. Patterns of $\delta^{13}\text{C}$ are systematic but less readily interpreted than those for $\delta^{18}\text{O}$.

In press: Deep Sea Research.

Supported by: NSF Grant OCE82-17644.

WHOI Contribution No. 5894.

PALEONTOLOGY

HANDBOOK OF CENOZOIC CALCAREOUS NANNOFOSSILS: VOLUME 1: DISCOASTERS VOLUME 2: GATHOLITHAE VOLUME 3: HELIOLITHAE

Marie-Pierre Aubry

This handbook represents an attempt to synthesize our present knowledge about Cenozoic calcareous nannofossils. A great many species have now been described from Cenozoic rocks all over the world together with a wealth of information concerning their stratigraphic occurrences, paleoecologic preferences, and phylogenetic relationships. Unfortunately, this information has been dispersed in the literature. A compilation of this data in a single work would make it much more useful. For this purpose, I have selected the handbook format, where the species can be arranged for easy comparison.

Published and in press: Micropaleontology Press, The American Museum of Natural History, New York.

Supported by: A consortium of oil companies.

WHOI Contribution Nos. 5995, 5996, and 5997.

GEOCHRONOLOGY OF THE EOCENE/OLIGOCENE BOUNDARY

W. A. Berggren

Current age estimates for the Eocene/Oligocene boundary range from ~33 Ma to ~38 Ma. A review is presented of the nature and methods employed in deriving these ages. Integrated studies employing the combined techniques of bio-, magneto-, and isotope chronology suggest a value between 36-37 Ma; the one preferred here is 36.6 Ma.

In press: Palaeogeography, Palaeoclimatology, Palaeoecology.
Elsevier.

Supported by: NSF Grants OCE80-19052 and OCE84-17040.

WHOI Contribution No. 5971.

NON-SYNCHRONEITY IN LATE CENOZOIC RADIOLARIAN EVENTS OF THE EQUATORIAL INDO-PACIFIC

David A. Johnson and Catherine A. Nigrini

A biostratigraphic study of Late Cenozoic Radiolaria in the equatorial Indo-Pacific shows an asymmetrical distribution between diachronous and synchronous events. A majority of synchronous events (15 out of 19) are last occurrences; the majority of diachronous events (10 out of 13) are first occurrences. Our results parallel those of Bretsky and Klofak on Late Ordovician marine invertebrates of eastern North America. Extinctions may be preferable to first occurrences in the selection of datum levels for the definition of biostratigraphic zonations and for correlation control within global time scales. The observed diachroneity for equatorial radiolarian events is 1 to 2 m.y., or several orders of magnitude greater than the nominal mixing time of the oceans; consequently the biological and physical exchange processes in association with speciation events may not follow simple advective mixing models.

Published in: Science, 230, 538-540.

Supported by: NSF Grant OCE85-00668.

WHOI Contribution No. 5964.

SYNCHRONOUS AND TIME-TRANSGRESSIVE NEOGENE RADIOLARIAN DATUM LEVELS IN THE EQUATORIAL INDIAN AND PACIFIC OCEANS

David A. Johnson and Catherine A. Nigrini

Fifty radiolarian events of early Pleistocene and Neogene age were identified in an east-west transect of equatorial DSDP sites, extending from the Gulf of Panama to the western Pacific and eastern Indian Oceans. Our objective was to document the degree of synchronicity or time-transgressiveness of stratigraphically-useful datum levels from this geologic time interval. We restricted our study to low latitudes within which morphological variations of individual taxa are minimal, the total assemblage diversity remains high, and stratigraphic continuity is well-documented by an independent set of criteria. Each of the five sites chosen (503, 573, 289/586, 214) was calibrated to an "absolute" time scale, using a multiple of planktonic foraminiferal, nannofossil, and diatom datum levels which have been independently correlated to the paleomagnetic polarity time scale in piston core material. With these correlations we have assigned "abso-

lute" ages to each radiolarian event, with a precision of 0.1-0.2 m.y. and an accuracy of 0.2-0.4 m.y. On this basis we have classified each of the events as either: (a) synchronous (range of ages <0.4 m.y.); (b) time-transgressive (i.e., range of ages >1.0 m.y.); and (c) not resolvable (range of ages 0.4-1.0 m.y.).

Our results show that, among the synchronous datum levels, a large majority (15 out of 19) are last occurrences. Among those events which are clearly time-transgressive, most are first appearances (10 out of 13). In many instances, taxa appear to evolve first in the Indian Ocean and subsequently in the western and eastern Pacific Ocean. This pattern is particularly unexpected in view of the strong east-to-west zonal flow in equatorial latitudes. Three of the time-transgressive events have been used to define zonal boundaries (the first appearances of Spongaster pentas, Diartus hughesi, and D. petterssoni). Our results suggest that biostratigraphic non-synchronicity may be substantial (i.e., greater than 1 m.y.) within a given latitudinal zone; one would expect this effect to be even more pronounced across oceanographic and climatic gradients.

We anticipate that the extent of diachroneity may be comparable for diatom, foraminiferal, and nannofossil datum levels as well. If this proves true, global "time scales" may need to be re-formulated on the basis of a smaller number of demonstrably synchronous events.

In press: Marine Micropaleontology.

Supported by: NSF Grant OCE85-00668.

WHOI Contribution No. 5965.

NEOGENE ANTARCTIC RADIOLARIA

David Lazarus

Radiolarians are abundant and well preserved in most Neogene sediments from the Southern Ocean. The present inventory of piston cores and DSDP drill cores has been used successfully to develop a biostratigraphic framework for the Neogene, although earlier portions of the biostratigraphy still need to be correlated to the absolute time-scale. Major differences in taxonomic composition in Recent sediments are closely associated with major circumpolar surface water fronts. These biogeographic differences extend back well into the Miocene and are apparent even at the family level. The origin and evolution of these endemic biotas are an important subject for evolutionary research. Biogeographic differ-

ences in Southern Ocean radiolarian assemblages have been used to study Pleistocene paleoceanography and paleoclimatology and could be similarly exploited to study the paleoceanographic evolution of the Southern Ocean throughout the Neogene.

Evolutionary and paleoceanographic studies of Neogene Antarctic radiolaria are presently limited by an extremely incomplete taxonomy prior to the Pleistocene, inadequate knowledge of pre-Pleistocene radiolarian biogeography, incomplete sedimentary sections, and lack of a reliable chronology in the early Neogene. These problems can be solved by additional taxonomic study, biogeographic analysis of existing pre-Pleistocene piston cores and drill cores, recovery of continuous sequences by the Ocean Drilling Program, and the application of new dating techniques. As this work is accomplished, Antarctic radiolaria will become increasingly important, both as subjects for evolutionary studies and as powerful tools for stratigraphic and paleoenvironmental analyses of the Neogene Southern Ocean.

Supported by: NSF Grants OCE79-19092 and DPP83-17087.

WHOI Contribution No. 6100.

THREE-DIMENSIONAL MEASUREMENT OF MICROFOSSIL MORPHOLOGY

David B. Lazarus

A three-dimensional digitizer system has been developed for rapid measurement of microfossil morphology. X and Y values are obtained via the combined use of a camera lucida attachment to the microscope and a digitizer tablet. Z values are automatically obtained from the fine-focus knob of the microscope. The system is based on inexpensive (<\$5,000) microcomputer components and has horizontal and vertical accuracies of better than one micrometer. A control program provides facilities for taking measurements, editing data, and formatting data for printout. All data are stored by the system in machine-readable form. The system is presently used to measure lengths, angles, and to collect shape data on fossil Radiolaria.

In press: Journal of Paleontology.

Supported by: NSF Grant DEB81-18743.

WHOI Contribution No. 5881.

TEMPO AND MODE OF MORPHOLOGIC EVOLUTION
NEAR THE ORIGIN OF THE RADIOLARIAN LINEAGE

P. prismatium

David Lazarus

Morphometric examination of cladogenesis and phyletic evolution in two late Neogene sister lineages of marine microfossils (Pterocanium prismatium and P. charybdeum, Radiolaria) from two equatorial Pacific sediment cores was undertaken to better understand the rate of cladogenesis and its relation to subsequent phyletic change. The origin of P. prismatium from P. charybdeum ~4 million years ago was estimated by Lazarus et al. (1985) to take place over an interval of ~500,000 years. Results show that the speciation event consists of two distinct phases. The first phase, cladogenesis, occurred relatively rapidly (on the order of 50,000 years). A second phase of relatively rapid divergent phyletic evolution away from the common ancestral state followed in both descendant branches and continued for at least 500,000 years after completion of the cladogenetic event. Net evolutionary rates over the next 2 million years appear to be much lower. Individual characters change by as much as 2 population standard deviations during cladogenesis and by a total of ~3 std. dev. over 2.5 million years of phyletic evolution. Up to 5 population standard deviations of change during $\leq 50,000$ years of cladogenesis and 7 additional S.D.'s of phyletic change over 500,000 years are observed in multivariate (discriminant function) indices of morphologic difference. The measured pattern does not appear to be either strictly "punctuated" or strictly "gradual," but instead shows features of both hypotheses.

Supported by: NSF Grant DEB81-18743.

WHOI Contribution No. 6001.

P E T R O L O G Y

LINKED EVOLUTIONARY DATA ARRAYS:
A LOGICAL STRUCTURE FOR PETROLOGIC
MODELLING OF MULTI-SOURCE, MULTI-PROCESS
MAGMATIC SYSTEMS

W. B. Bryan

Many of the classical studies in igneous petrology were concerned with "parentage" and "lineage" of igneous rock series. Indeed, the "liquid line of descent" is still a popular and useful concept in ex-

perimental petrology. However, the classical assumption that a rock series is derived from a single parent through operation of a single process is no longer an adequate conceptual basis for most modern petrologic studies. Some of the most compelling evidence for multi-source, multi-process magma genesis has come from studies of ocean ridge basalts. Compared to continental basalts, those at oceanic spreading centers might be expected to be erupted relatively directly from their mantle source with little modification by interactions with the crust; yet comprehensive studies of their petrography, major and trace elements, and isotopic ratios show significant heterogeneity on both local and regional scales (Bougault et al., 1979; Machado et al., 1982). Although convincing evidence has been presented for operation of simple low-pressure crystal melt equilibria and also of magma mixing in specific sample subsets (Dungan and Rhodes, 1978; Bryan et al., 1981), these processes usually are unable to explain all of the co-variations in incompatible trace elements, major elements, and isotopic ratios within the associated total data set. More complex processes, along with substantial source heterogeneity, are implied by these data.

Curiously, although the recognition of a multi-source, multi-process evolutionary history for most igneous rock series would seem to require utilization of the maximum number of compositional constraints on models, "old-fashioned" major element data are now commonly bypassed for this purpose.

In press: Journal of Geophysical
Research, ISEM Symposium Volume.

Supported by: McDonnell Center for
Planetary Research.

WHOI Contribution No. 5891.

VOLCANIC PROCESSES AND THE EVOLUTION OF
LAYER 2 IN THE WESTERN NORTH ATLANTIC

W. B. Bryan and F. A. Frey

The nature of the volcanic basement rocks in the Western North Atlantic must be deduced from samples obtained from a relatively few, widely spaced deep drill holes. Of those holes which succeeded in penetrating a significant thickness of crust (100 m or more), only a few have sufficiently high core recovery to allow detailed inferences about the morphology and structure of individual flows and of petrographic and compositional variation within specific cooling units. The available data suggest that there is no simple variation, either

in initial magmatic chemistry or in the nature and degree of alteration chemistry and mineralogy, with depth or with time. Indeed, some isotopic evidence suggests that low-temperature alteration proceeds to varying degrees of completion, partly dependent on rates of burial and length of exposure of rock basement, within the first few million years of existence of new crust. Subsequent changes, if any, proceed at a much reduced rate as sediment cover increases.

Older ocean crust recovered from holes drilled parallel to, and at various distances from, the modern Mid-Atlantic Ridge are sometimes significantly different in critical major element or trace element ratios, or both, compared to samples recovered from the modern spreading center at the inferred source of the older material. Also, important differences in rare earth enrichments and other critical trace element ratios may appear between different volcanic flow units even within a single drill hole. These geochemical inconsistencies resemble those which also have been demonstrated among closely associated samples recovered from the more intensively sampled areas of the Mid-Atlantic Ridge, such as FAMOUS and 22°N. While the exact reasons for these differences remain controversial, they are consistent with hypotheses that postulate mantle source heterogeneity on a fine scale, perhaps involving veining or upwelling of small magma diapirs representing different melting histories.

Basalts associated with the earliest stages of rifting between North America and Africa are preserved in exposed Mesozoic strata on the margins of both continents. These basalts show some regional north-south variations of a similar nature and magnitude to those displayed by modern ocean ridge basalts along the corresponding modern segment of the Mid-Atlantic Ridge. However, there is also a strong geochemical "over-print" on these basalts that must reflect contamination by continental crust, derivation from a special subcontinental mantle, or both. Also, in both North America and Morocco, there is a reasonably well-defined variation with time toward a more "oceanic" geochemical signature. Unfortunately, some critical isotopic and trace element data are still not available for key samples, and the different effects of subaerial and submarine alteration also complicate comparative studies. As rifting continued, volcanic events became more intermittent and localized, with a trend toward more highly alkaline geochemistry. A similar trend is recorded in the continental basalts associated with rifting between Greenland and Northern Europe. It is a curious fact that this alkaline volcanism

has continued along the eastern margin of the Atlantic, as exemplified by the Canary Islands, while such activity seems to have ended completely along the Western Atlantic margin in the late Cretaceous or early Tertiary. Also, the renewal of alkaline volcanism in Bermuda, after an apparent 60 m.y. of quiescence, remains a problem.

Much more complete sampling and detailed laboratory data will be required to support detailed comparisons between volcanic rocks on originally adjacent continental blocks or between older continental basalts and modern ocean ridge basalts. However, the available data suggest that processes of magma production and eruption may have been broadly similar throughout the whole period of spreading of the North Atlantic.

In press: "The Geology of North America: The Western Atlantic. Geological Society of America.

Supported by: Ocean Drilling Project, NSF.

WHOI Contribution No. 5989.

PETROLOGY AND GEOCHEMISTRY OF BASALTS FROM THE AMERICAN-ANTARCTIC RIDGE, SOUTHERN OCEAN: IMPLICATIONS FOR THE WESTWARD INFLUENCE OF THE BOUVET MANTLE PLUME

Anton P. le Roex, Henry J. B. Dick, Arch M. Reid, Fred A. Frey, Anthony J. Erlank and Stan R. Hart

Ridge segments and fracture zones from the American-Antarctic Ridge have been systematically dredge sampled from ~4° to ~18°W. Petrographic studies of the dredged basalts show that the dominant basalt variety is olivine-plagioclase basalt, although olivine-plagioclase-clinopyroxene basalt is relatively common at some localities. Selected samples have been analyzed for major and trace elements, rare earth elements, and Sr and Nd isotopes. These data show that the majority of samples are slightly evolved ($Mg\# = 69-35$) N-type MORB, although a small group of samples from a number of localities have "enriched" geochemical characteristics (T- and P-type MORB).

These different types of MORB are readily distinguished in terms of their incompatible trace element and isotopic characteristics -- N-type MORB have high Zr/Nb (17-78), Y/Nb (4.6-23) and $^{143}Nd/^{144}Nd$ (0.51303-0.51308) ratios, low Zr/Y (2.2-4.2) and $^{87}Sr/^{86}Sr$ (0.70263-0.70295) ratios and have $(La/Sm)_N < 1.0$; T-type MORB have lower than chondritic Zr/Nb ratios (8.8-15.5), relatively low Y/Nb (1.9-4.3) and $^{143}Nd/^{144}Nd$ (0.51296-

0.51288) ratios and relatively high Zr/Y (3.1-4.7), $^{87}\text{Sr}/^{86}\text{Sr}$ (0.70307-0.70334) and (La/Sm)_N (1.1-1.5) ratios; the single sample of P-type MORB has low Zr/Nb (6.3), Y/Nb (0.9) and $^{143}\text{Nd}/^{144}\text{Nd}$ (0.51287) ratios and high Zr/Y (7.1), $^{87}\text{Sr}/^{86}\text{Sr}$ (0.70351) and (La/Sm)_N (2.4) ratios. The geochemical characteristics of this sample are essentially identical to those of the Bouvet Island lavas.

Geochemically "enriched" MORB are less abundant on the American-Antarctic Ridge than on the Southwest Indian Ridge but their geochemical characteristics are identical. The compositions of T- and P-type MORB are consistent with a regional mixing model involving normal depleted mantle and Bouvet plume type magma. On a local scale, the composition of T-type MORB is consistent with derivation from depleted mantle which contains ~4% veins of P-type melt.

We propose a model for the evolution of the American-Antarctic Ridge lavas in which N-type MORB is derived from mantle with negligible to low vein/mantle ratios, T-type MORB is derived from domains with moderate and variable vein/mantle ratios, and P-type MORB is derived from regions with very high vein/mantle ratios where vein material comprises the major portion of the melt. The sparse occurrence of "enriched" lavas and by implication "enriched" mantle beneath the AAR some distance (500-1200 km) from the Bouvet plume location is interpreted to be the result of lateral dispersion of enriched mantle domains by asthenospheric flow away from the Bouvet mantle plume towards the American-Antarctic Ridge.

Published in: Contributions to Mineralogy and Petrology, 90, 367-380.

Supported by: NSF Grant DPP83-16490.

WHOI Contribution No. 5943.

SEDIMENTOLOGY

HYDRODYNAMIC CONTROLS ON SEDIMENT TRANSPORT IN WELL-MIXED BAYS AND ESTUARIES

D. G. Aubrey

Shallow bays and estuaries with negligible gravitational circulation respond to tidal forcing in a systematic manner determined primarily by channel geometry, bay geometry, and frictional effects. These characteristics impart a tidal distortion to the bay, which can be represented by

growth or decay of overtides and compound tides which experience down-channel evolution in amplitude but which remain phase-locked to the parent tides throughout the bay. This systematic tidal response leads to either a flood-dominated bay with shorter, more intense flood tides or an ebb-dominated bay with shorter, more intense ebb flows. Distortion of the tidal velocities leads to significant nonlinear growth of harmonics of the forcing tides, imparting an asymmetry to tidal velocity and near-bed shear stress time history. For coarse sediment transport, this shear stress asymmetry leads to a net transport of sediment in the direction of tidal dominance. For flood-dominance, the bay will tend to fill in; for ebb-dominance, the bay will be self-flushing. For fine sediment transported as suspended load, ignoring gravitational effects, the net transport is determined in part by the sediment fall velocity and time scale of tidal flow reversal as well as the height to which sediment is suspended. A heuristic argument indicates that the net suspended transport can be either in the same or opposite sense as the tidal distortion. Improvements on estimates of net sediment transport require more complete descriptions of lateral variability in channel flow, biological and chemical effects, and bottom boundary layer modeling.

In press: Physics of Shallow Bays and Estuaries. Springer-Verlag.

Supported by: NOAA Sea Grant NA80-AA-D-00077 and the Coastal Research Center, WHOI.

WHOI Contribution No. 5908.

CALCIUM CARBONATE SUSPENDED IN ARABIAN GULF AND RED SEA WATERS: BIOGENIC AND DETRITAL, NOT "CHEMOGENIC"

J. P. Ellis and J. D. Milliman

The warm saline waters of the Arabian Gulf and Red Sea are supersaturated with respect to aragonite and magnesian calcite. Despite the local dominance of these phases in the Arabian Gulf sediment and their general abundance in southern Red Sea sediments, little or no evidence of "chemogenic" carbonate is found in the overlying waters; suspended carbonate grains are either biogenic or detrital. Precipitation of calcium carbonate appears limited to bottom or interstitial waters.

Published in: Journal of Sedimentary Petrology, 55, 805-808.

Supported by: ONR Contract N00014-81-C-0009.

WHOI Contribution No. 5917.

EVALUATION OF A LASER DIFFRACTION SIZE ANALYZER FOR USE WITH NATURAL SEDIMENTS

I. N. McCave, R. J. Bryant, H. Cook
and C. A. Coughanowr

Several authors in the 1970s suggested ways of inferring the size distributions of particles in suspension from the angular distribution of forward-scattered light (Cornillault, 1972; Weiss and Frock, 1976; and Swithenbank et al., 1976, 1977). These papers have led to the construction of instruments by CILAS (France), Leeds and Northrup (U.S.A.), and Malvern Instruments (U.K.), respectively. The present study has evaluated the Malvern Instruments Laser Particle Sizer Type 3600 E which employs the principles set out by Swithenbank et al. (1976, 1977).

In press: Journal of Sedimentary
Petrology Methods Issue.

Supported by: ONR Contract N00014-82-C-00019 NR-083.

WHOI Contribution No. 6027.

SILICOFLAGELLATES AND *Actiniscus*: VERTICAL FLUXES AT PACIFIC AND ATLANTIC SEDIMENT TRAP STATIONS

Kozo Takahashi

Vertical fluxes of silicoflagellate skeletons were measured in meso- and bathypelagic zones at four PARFLUX sediment trap stations located in the Pacific and Atlantic oceans. The average flux measured at several depths ranged from 35×10^3 skeletons/m²/day at the Pacific gyre (P₁) station to 424×10^3 skeletons/m²/day at the Panama Basin (PB) station. The skeletal fluxes at these stations constituted a few percent or less of the total biogenic opal flux.

The fluxes measured at Station P₁, as well as the relative abundance of assemblages, were relatively constant throughout the depths. At Station PB, while relative abundance of assemblages was constant throughout the depths, the flux measured at mesopelagic depths was threefold greater than that in bathypelagic zones. At the equatorial Atlantic station, Station E, a slight increase toward the bathypelagic zone was correlated with gradual change in the relative abundance of two predominant

taxa, suggesting seasonality. Aggregate forms of vertical settling were observed at Station E₁; the number of skeletons in the aggregates was more than one-half of the total number in the mesopelagic zone and it decreased with increasing depth.

The percent abundance of *D. messanensis* and *D. pulchra* was correlated with organic carbon flux at the four stations. Preservation of the skeletons in Holocene sediment at Station P₁ was less than one percent of the silicoflagellate flux.

In Press: Ocean Biocoenosis. S.
Honjo, ed. Micropaleontology
Press.

Supported by: NSF Grants OCE80-19386
and OCE82-08638.

WHOI Contribution No. 5876.

SEASONAL FLUXES OF PELAGIC DIATOMS IN THE SUBARCTIC PACIFIC, 1982-1983

Kozo Takahashi

An assessment of the vertical flux of pelagic diatoms was conducted on PARFLUX sediment trap samples collected during September 1982 through September 1983 at subarctic Pacific Station PAPA (50°N, 145°W; water depth 4200 m). The time series sediment trap samples were collected for 11- to 16-day periods during the year; a total of 24 samples represent a full year's record of flux. Seasonal fluxes of eighteen encountered taxa are reported. All of the taxa fall into one of five different types of seasonal flux patterns. Generally, taxa in types 1-3 are indicators for high mass, opal, and organic carbon fluxes based on correlation analysis with mass and opal fluxes. Among them, *Ch. atlanticus*, *R. styliformis*, and *As. robustus* are the best indicators for production based on correlations of their fluxes with mass or opal fluxes. Unique signals from *C. marginatus* are present in the October-December high flux season and the January-March high percentage values.

Based on flux maxima and minima and species components, two depth samples from 1000 m and 3800 m were cross-correlated. The correlations show that the two depth samples are generally offset by one sample interval of two weeks. The sinking speeds of diatoms are estimated to be approximately 175 md^{-1} regardless of taxa, size, or morphology, invoking the necessity of aggregated and accelerated sinking. Diatom fluxes of various taxa measured at 1000 m and 3800 m with one sample offset are generally nearly equal, implying that no

significant dissolution takes place en route to the sea floor. Approximately 2% of the diatom flux is preserved in the surface sediments. A significant alteration in percentages of diatom taxa takes place on the sea-floor, typically shown by the percent decrease of D. seminae -- 87% in flux compared to 30% in surface sediments.

Supported by: NSF Grant OCE85-02472.

WHOI Contribution No. 6107.

ECOPHENOTIPIC SIZE CHANGES OF
Coscinodiscus marginatus (DIATOM)

Kozo Takahashi

The valve diameters of a diatom taxon, Coscinodiscus marginatus, were measured using year-long, 1982-1983, time-series sediment trap samples recovered from sub-arctic Pacific Ocean Station PAPA. A cyclic trend in size changes of valves was observed in seasonal flux samples collected at 3800 m depth. Results of actual valve size measurements and percentages of valve counts in fine and coarse size fractions show a parallel trend, suggesting the significance of valve counts for implying size distribution. Similar valve measurements were conducted on fossil specimens taken from samples of a gravity core recovered at the same Station PAPA. The size distributions of the valves of C. marginatus from the past several thousand years are similar to that of the present day. The valve size from each time slice is comparable to that of our time-series samples. On the other hand, the size of the C. marginatus valves from the last glacial maximum (~18,000 yrs. B.P.) was markedly different from that of present day counterparts. They were relatively large and the size distribution was strongly, negatively skewed.

Supported by: NSF Grant OCE85-02472.

WHOI Contribution No. 6106.

I N S T R U M E N T A T I O N

MEASUREMENT ERRORS FOR
ELECTROMAGNETIC CURRENT METERS

David G. Aubrey

The Nearshore Sediment Transport Study (NSTS) field experiments relied on Marsh-McBirney electromagnetic current meters to

provide estimates of currents in the surf zone for hydrodynamics and sediment transport modeling. These meters were chosen because of their history of successful use in previous surf zone studies, due to their compactness and durability in this rough environment. The present work was motivated by examination of the NSTS experimental data from Santa Barbara, CA, in which the higher-order velocity moments calculated from current meter time series showed a time-variability not obviously related to time scales of change of forcing (e.g., wave groupiness, infragravity waves) and by field studies which show persistent offshore near-bottom flow which is not yet satisfactorily explained by near-shore circulation theories. Because of the importance of these quasi-steady flows and higher order velocity moments to sediment transport in the nearshore, the present study examined, under carefully controlled laboratory conditions, the dynamic response of electromagnetic current meters (EMCM) typically used for field experimentation.

In press: Nearshore Sediment Transport Study Monograph.

Supported by: NOAA Sea Grant NA80-AA-D-00077; U.S. Army Corps of Engineers Contract DACW/2-82-C-0014; and the Coastal Research Center, WHOI.

WHOI Contribution No. 5916.

T E C H N I C A L R E P O R T S

TWO YEAR TIME-SERIES FLUXES OF
SILICOFLAGELLATES AND Actiniscus: SIZE
FRACTIONED RESULTS FROM SUBARCTIC
PACIFIC STATION PAPA, 1982-1984

Kozo Takahashi

A seasonal flux study of silicoflagellates and Actiniscus was conducted at sub-arctic Pacific Station PAPA (50°N, 145°W; water depth 4200 m) during September 1982 through August 1984 using PARFLUX time series sediment traps deployed at 1000 m and 3800 m depths. The time series sediment trap samples were collected for 4- to 16-day periods depending on the samples; most of the samples were collected for 14- to 16-day periods. A total of 47 continuous samples represents nearly a two-year record of the fluxes of silicoflagellate and Actiniscus taxa at 3800 m depth. An additional 12 samples from 1000 m represent

a continuous 6-month period which provides a pair of samples from two depths of each time series. Analysis of the paired samples is essential to understand particle sinking processes. Seven silicoflagellate taxa, several additional variants of silicoflagellates, and the Actiniscus pentalsterias group were enumerated, based on a census of four wet sieved size fractions: 250-1000µm, 125-250µm, 63-125µm, and <63µm. A total of more than 32×10^3 specimens were identified to species level and counted in this study. Statistics of the counts are given. The fluxes of silicoflagellate taxa of all four size fractions are graphically presented. This report provides a detailed data base for further investigations of seasonal silicoflagellate fluxes in the area.

Supported by: NSF Grant OCE85-02472.

WHOI Technical Report 85-40.

PELAGIC DIATOM FLUXES I:
SIZE FRACTIONED TIME-SERIES RESULTS
FROM SUBARCTIC PACIFIC STATION PAPA
DURING 1982-1983

Kozo Takahashi, Danielle N. Povio,
John D. Billings and Steven J. Manganini

A time series vertical flux assessment of pelagic diatoms was conducted during September 1982 through September 1983 at subarctic Pacific Station PAPA (50°N, 145°W; water depth 4200 m) using PARFLUX sediment traps deployed at 1000 and 3800 m. The time series sediment trap samples were collected for 11- to 16-day periods during the year; a total of 24 samples represent a full year's record of flux. Eighteen taxonomic groups of diatoms were enumerated, based on a census of four wet-sieved size fractions: 250-1000µm, 125-250µm, 63-125µm, and <63µm. In order to study the sinking processes of diatoms, detailed information was separated from frustules. Size-fractioned fluxes of all the counting groups are graphically presented, which provides a data base for further investigations.

Supported by: NSF Grant OCE85-02472.

WHOI Technical Report 85-37.

DEPARTMENT OF OCEAN ENGINEERING
Robert C. Spindel, Department Chairman

ACOUSTIC SIGNAL
PROCESSING

BANDWIDTH EXTRAPOLATION THROUGH
ITERATIVE DECONVOLUTION

Jules S. Jaffe

The topic of the inversion of large systems of linear equations in order to deconvolve signals has been under intense study for several decades. Although large scale computers have extended our ability to process a great deal more information, the application of inverse techniques to large one, two and three dimensional systems has remained a problem. The most fruitful areas of research in solving these problems have been to employ iterative techniques (Frieden, 1978, Gershberg, 1974). This paper will describe the initial performance and subsequent improvements that we have made to one of these algorithms, the Jansson-Van Cittert algorithm (Jansson, 1968). Our interest in these algorithms has been motivated by the possibility of using them to obtain higher bandwidth signals in Acoustic Tomography. We are also interested in applying these techniques in order to extrapolate information into regions of Fourier space that may be unknown, in standard tomography, due to limited angular information.

Our observations of the performance of the Jansson-Van Cittert algorithm led us to conclude that the algorithm is very sensitive to noise. Another problem was that the algorithm converged very slowly. A great improvement in both convergence rate and noise immunity was obtained through a modification of the algorithm (Jaffe, 1985). Our studies have progressed and we have been able to further improve the implementation that we proposed at that time. In particular, we have explicitly formulated the improved algorithm as a minimization problem which will minimize an appropriate norm. This norm consists of two terms: 1) a least square fit to the data and 2) a smoothness constraint. Examples of the implementation of the algorithm will be presented for one dimensional and two dimensional signals of interest.

Supported by: ONR Contract
N00014-85-K-0369.

WHOI Contribution No. 6129.

SUPER RESOLUTION OF ACOUSTIC TOMOGRAPHY
MULTIPATH DATA

Jules S. Jaffe

Acoustic tomography is an experimental method that allows the spatio-temporal structure of the ocean to be measured. The technique consists of deploying a number of transmitting and receiving acoustic devices and measuring the systematic perturbations in the received sound. Although only a single pulse train of sound is transmitted at a given time, multiple pulses are received due to the physics of the propagation of sound in the ocean. The separation of closely spaced received pulses is of interest to oceanographers as the resolution of the reconstructed ocean sound profile increases with the number of identifiable pulses. This paper describes the application of a super resolution (bandwidth extrapolation) technique that has been applied to acoustic tomography data. Using this algorithm, we have been able to achieve better resolution of the incoming arrival times.

In this work, we have assumed that the collection and subsequent preprocessing of the tomographic data can be adequately represented by a transfer function. This implies that we can apply deconvolution techniques to reconstruct the original signal. Moreover, the application of iterative deconvolution methods have been shown to not only correct for a given transfer function but also, in some cases, to increase resolution via the extrapolation of frequency information. Although these algorithms are not as well understood as one would hope, it has been determined that this bandwidth extrapolation can be achieved through the use of linear and nonlinear constraints. This study was initiated in order to study the application of a specific formulation of one of these algorithms, the Jansson-Van Cittert algorithm [P.A. Jansson, R.H. Hunt, E.K. Plyer, J. Opt. Soc. Am., 58, 1665 (1968)] to the acoustic tomography data.

Initial implementation of a technique was aimed at exploring its effect on noiseless data. In this case, the algorithm succeeded quite well in obtaining a factor of 3 in resolution enhancement for a typical acoustic tomography transfer function. Additional experiments which included noise indicated that this factor of 3 was obtainable in the presence of S/N ratios down to 4:1. However, some amplification of noise does occur if the algorithm is allowed to iteratively converge.

Modification of this algorithm has been undertaken in order to achieve better performance. Reformulation of the iterative update step has resulted in a large

increase in the convergence rate. In addition, the noise sensitivity of the algorithm has been decreased by imposing real space smoothing constraints on the solution. In summary, we have demonstrated that an iterative bandwidth extrapolation algorithm can be successfully applied to achieve higher resolution of acoustic tomography data.

Published in: Proceedings of the 1985
IEEE International Conference on
Acoustics, Speech and Signal Processing.

Supported by: Pew Memorial Trust.

WHOI Contribution No. 5852.

SYNTHETIC APERTURE IMAGE HOLOGRAPHY

Tomamasa Sato and Jules S. Jaffe

This paper describes the underwater imaging method of "Synthetic Aperture Image Holography" which has real-time imaging capability. This method utilizes image holography and computer synthetic aperture techniques. The imaging system consists of the acoustic lens, ultrasound receiving and transmitting arrays, and the computer. The diameter of the acoustic lens is smaller than the aperture of the transmitting array. By transmitting the ultrasound from the elements of the transmitting array one by one, the phase and amplitude of the lower resolution images (image holograms), focused by the acoustic lens, are detected by the receiving array. After obtaining all of the image holograms, the final image is calculated by synthesizing all of these image holograms in the computer. The results of one-dimensional underwater experiments are shown. The conceptual design of a real-time imaging system that is based on this method is also presented.

Supported by: Pew Foundation.

WHOI Technical Report 85-5.

LOWER BOUNDS IN PARAMETER ESTIMATION

A. J. Weiss and E. Weinstein

We formulate a general class of lower bounds on the minimum attainable mean square error (MSE) in parameter estimation and show that the Cramer-Rao, the Bhattacharyya, and Bobrovsky-Sakai bounds are special cases in the class. We then propose a lower bound in the class that is at least as tight and, in many cases,

significantly tighter than the above mentioned bounds. The proposed bound is simple to analyze and compute, it is free from bias and regularity assumptions, it readily incorporates any prior statistical information concerning the parameter, and it readily generalizes to the estimation of vector parameters and any given function of the parameters. The proposed bound is also compared with the Belini-Tartara and Chazan-Ziv-Sakai bounds and with the Barankin lower bound.

Using the proposed bounds, we derive closed form analytical formulae for calculating tight lower bounds on the attainable MSE in estimating signal parameters imbedded in a random process and show that these formulae can be applied to analyze ambiguity and threshold effects in problems of that type.

Supported by: Naval Underwater Systems
Center, New London, CT.

W.H.O.I. Contribution No. 5991.

F L U I D

D Y N A M I C S

LARVAL SETTLEMENT OF SOFT-SEDIMENT INVERTEBRATES: SOME PREDICTIONS BASED ON AN ANALYSIS OF NEAR-BOTTOM VELOCITY PROFILES

Cheryl Ann Butman

During settlement, planktonic larvae may actively select habitats, they may be passively deposited onto the seabed, or both processes may apply, but for different spatial or temporal scales or for different flow regimes. Proposing realistic settlement scenarios involving both passive deposition and active habitat selection can profit from a priori analyses of near-bed flow characteristics relative to known aspects of larval biology (i.e., swim speeds and fall velocities). Toward this end, smooth-turbulent velocity profiles were calculated for everyday tidal flows at a shallow subtidal study site, where continuous near-bed flow measurements were available. Velocity profiles were constructed for a realistic range of flow conditions. Rough-turbulent flow profiles also were calculated, assuming storm waves periodically are sufficient to resuspend sediments and make a rippled seabed. Under most flow conditions analyzed, mean flow speeds exceed maximum larval swim speeds, even to within

tenths of millimeters from the bed. In the smooth-turbulent flows, larvae generally would encounter no opposed velocity if they swam vertically in the viscous sublayer to heights of about 0.25-cm above the bed. In rough-turbulent flows, eddies regularly penetrate to within tenths of millimeters of the bed, so larvae would experience eddy velocities with components in all directions very close to the bed. It is concluded that, at least at this study site, larvae probably do not search for preferred habitats by horizontal swimming. Larvae may swim vertically down to test the substrate and then swim vertically up to be advected downstream. However, it also is noted that measured larval swim speeds and fall velocities are about the same order of magnitude, so at best, larvae may only be able to maintain position when swimming vertically.

Supported by: PEW Memorial Trust; NSF Grant OCE-85000875; Sea Grant R/P-21; NOAA Contract NA84AA-D-00033; and WHOI Coastal Research Center.

WHOI Contribution No. 6046.

SEDIMENT TRAP BIASES IN TURBULENT FLOWS: RESULTS FROM A LABORATORY FLUME STUDY

Cheryl Ann Butman

Several cylindrical and noncylindrical sediment trap designs were tested in a recirculating steady-flow flume. The laboratory study was conducted to achieve dynamic and geometric-similarity to conditions in a specific field environment where traps eventually would be deployed. Relative (to a "standard" trap design) particle collection efficiencies of the traps were quantified in 10 cm/sec turbulent flows that were continuously seeded with particles having fall velocities of about 10^{-3} to 10^{-2} cm/sec (the upper range of silt-sized quartz sediments). The nature of flow through the trap mouths was qualitatively described using dye.

The following trap biases were demonstrated in the study. For cylinders, efficiency decreased over a range of increasing trap Reynolds number (R_t) when aspect ratio (H/D) was held constant, and efficiency increased over a range of H/D when R_t was held constant. Baffling cylinders with various H/D , but constant R_t , gave mixed results. Most surprising, any disturbance to flow near the trap mouth or through the trap tended to increase between-replicate variability. For noncylindrical traps, small-mouth, wide-body traps overcollected particles and

funnel-type traps tended to undercollect particles, relative to cylinders of the same height and mouth diameter.

The biases demonstrated here are for specific parameter combinations and cannot be generalized outside the range of values tested. The results do indicate that significant biased collections are possible by a variety of trap designs and may be flow-regime dependent. Trap-users thus are urged to interpret vertical flux results with caution. Detailed quantitative studies of trap biases for the ranges of conditions common in field trapping environments and process-oriented studies of physical trapping mechanisms are needed before it will be possible to declare any trap an unbiased collector in ocean flows.

Supported by: WHOI Coastal Research Center; Education Program, WHOI; Diving Equipment Manufacturers Association; Association for Women in Science (Predoctoral Award); NSF (Dissertation Improvement Grant); NOAA National Ocean Survey/Sea Grant Fellowship NA80-AA-D00077; U.S. Geological Survey (Woods Hole, MA); and Pew Memorial Trust.

WHOI Contribution No. 6063.

PREDICTIONS OF SEDIMENT TRAP BIASES IN TURBULENT FLOWS: A THEORETICAL ANALYSIS BASED ON OBSERVATIONS FROM THE LITERATURE

Cheryl Ann Butman, William D. Grant
and Keith D. Stolzenbach

The physical variables affecting the trapping of particles in sediment collectors are grouped into a set of six dimensionless parameters, as a function of a dimensionless particle collection efficiency, E . Relevant laboratory studies on sediment trap biases are evaluated to determine the quantitative dependence between E and three of the parameters, trap Reynolds number, the ratio of flow speed to particle fall velocity, and the ratio of trap height to mouth diameter and trap geometry. We find that few of the parameters have been systematically tested in the laboratory and that trap Reynolds number-similarity for field conditions is maintained only for the slowest flow speeds and/or smallest trap diameters. A physical description is given for particle trapping based on observations of flow through traps, the mass balance for particles entering and leaving traps, and a definition of particle collection efficiency. Any mechanism resulting in biased

trap collections affects the mass balance such that collection efficiency deviates from one. This leads to the development of simple physical models to account for the observed relationships from the literature review.

Specific testable hypotheses for biased trapping by straight-sided cylinders and noncylindrical traps are presented; for fixed values of the other two parameters, collection efficiency of cylinders may decrease over some range of increasing trap Reynolds number, decrease over some range of decreasing particle fall velocity, and increase over some range of increasing trap aspect ratio. Traps will be undercollectors or overcollectors depending on the specific mechanisms causing the biased collections. Predicting specific biased collections for noncylindrical traps is more complex but, in most cases, small-mouth, wide-body traps will be overcollectors and funnel-type traps will be undercollectors. Characteristics of particle collecting traps require thorough and careful investigation in the future and parameter combinations representative of field conditions where traps are deployed must be tested.

Supported by: WHOI Coastal Research Center; Education Program, WHOI; Diving Equipment Manufacturers Association; Association for Women in Science (Predoctoral Award); NSF (Dissertation Improvement Grant); NOAA National Ocean Survey/Sea Grant Fellowship NA80--AA-D00077; U.S. Geological Survey (Woods Hole, MA); and Pew Memorial Trust.

WHOI Contribution No. 5939.

THE CONTINENTAL SHELF BOTTOM BOUNDARY LAYER

W. D. Grant and O. S. Madsen

An important category of geophysical boundary layer flows is the bottom boundary layer over the continental shelf. The water motion on the shelf is driven by winds, tides, density differences, atmospheric pressure gradients and the sea surface slope. The relationship between the boundary layer characteristics and the externally driven fluid motions is affected by the highly nonlinear friction processes in the boundary layer, and the relationship takes on varying degrees of complexity dependent upon the types of external forcing present.

Bottom boundary layers are regions of turbulent mixing of mass, momentum, and heat. Frictional dissipation of energy

takes place in boundary layers and plays an important role in momentum balances. Bottom boundary layers are the interface where exchanges of particles, chemicals and organisms between seabed and overlying water column take place. The recent focus on continental shelf boundary layers stems from interest in several contemporary topics in oceanography and engineering.

The first of these topics is understanding wind-driven coastal circulation. Recent work indicates that the presence of surface waves over rough bottoms results in a significant increase in the bottom frictional terms over previous estimates and in additional variability of friction across the shelf. Due to the increased bottom friction, the thickness of the bottom boundary layer is considerably larger than previously estimated and in storms the majority of the water column over the shelf is frictionally dominated. Most models of wind-driven shelf circulation (Allen 1980) assume the surface and bottom layers of frictional influence to be small compared to the water depth; therefore, this assumption needs to be examined.

Another topic, sediment transport is highly dependent on boundary layer dynamics. Prediction of surface waves in shallow waters is related to the boundary layer dynamics through effects of bottom friction on wave dissipation. The shelf velocity field and mixing are important to primary productivity. Recent interest by the biological sciences in the role played by hydrodynamics in determining the distribution of benthic communities and in feeding mechanisms of various biota has fostered considerable interest in the role of nearbottom flows and mixing on these biological communities.

While drawing on many aspects of previous review of boundary layer and continental shelf circulation and sediment transport dynamics, the intent of the present review is to concentrate on the special features of the continental shelf wind-driven bottom boundary layer and the associated theoretical, observational, and experimental progress.

We describe what is known about the dynamics of the continental shelf bottom boundary layer and relate this knowledge back to an idealized boundary layer picture to provide physical interpretations of the basic parameters. The presence of fluid motions covering a wide band of frequencies presents a complex environment in which to make and interpret measurements. Some of these problems are reviewed in the last section.

Published in: Annual Review of Fluid Mechanics, 18, 265-305, 1986.

Supported by: NSF Grant OCE-8403249;
NOAA Sea Grant NA84AA-D-00033; and
ONR Contract N00014-C-85-0001.

W.H.O.I. Contribution No. 5952.

MODELING TIME DEPENDENCE IN A TIDAL BOUNDARY LAYER

Thomas F. Gross

Although the rate of acceleration and deceleration in a depth limited tidal flow can be quite large, it has been found that quasi-steady logarithmic models or steady eddy diffusivities can explain the turbulent field quite well (Gross and Nowell 1983; Long 1981). A simple, time dependent model was devised based on kinetic energy closure (Bradshaw 1967) to simulate a depth-limited tidal boundary layer without the assumption of a time independent eddy diffusivity. Computer solutions revealed that the parameter $S = u_s/\delta\Omega$ (u_s is a turbulent velocity scale, δ is depth, Ω is tidal frequency) governs the phasing of the velocity to the forcing pressure gradient. However, for values of S reasonable for depth limited estuarine tidal flow, the ratio of the turbulent energy production-dissipation balance to rate of change of turbulent energy is always quite large, indicating that the turbulent adjustment rate is fast enough for the flow to be modeled with quasi-steady techniques.

Supported by: NSF Grant OCE80-18304
and ONR Contract N00014-C-85-0001.

W.H.O.I. Contribution 5979.

SPECTRAL SCALING IN A TIDAL BOUNDARY LAYER

Thomas F. Gross and Arthur R. M. Nowell

The simple scaling of a tidal bottom boundary layer by the shear velocity, u_* , and the distance to the wall describes well the mean flow field. To test the full extent of this scaling, measurements were made of the turbulence spectra in a natural tidal flow and a steady canal flow. The scaling of the turbulence spectra by the distance to the wall works only when the ratio of spectral strain rate to the mean shear is large. Under these conditions, estimates of shear velocity, u_* , based on the dissipation derived from the magnitude of the inertial range of the spectra were found to agree to within 10 percent with estimates of the shear velocity from the mean velocity profiles and Reynolds stress. Within the

10 percent error bounds no effects ascribable to time dependence in the tidal spectra were discerned, and hence the simple scaling of the momentum field by u_* and z may be used for higher order moments.

Supported by: NSF Grant OCE80-18304.

WHOI Contribution No. 5860.

HYDRODYNAMIC FORCE ON CIRCULAR CYLINDERS

Ole Secher Madsen

The determination of the hydrodynamic force per unit length of a circular cylinder moving in a plane perpendicular to its axis in a nonuniform unsteady flow of an ideal fluid of infinite extent is formulated as a series expansion in the small parameter ka , where a is the cylinder radius and k^{-1} the length scale of the nonuniformity of the flow. Neglecting terms of order $(ka)^2$ and higher, the force per unit length is found to be in agreement with Taylor's (1928) result for a strictly two-dimensional flow in which the cylinder axis is perpendicular to the plane of flow. For the general three-dimensional case, the present result is, however, at variance with the customary Morison formulation of the inertia force associated with nonuniformity of the flow. The nature of these differences and their significance are discussed in the context of the prediction of inertia forces on piles in nonlinear waves.

Supported by: Massachusetts Institute
of Technology Grant OSB-94188.

WHOI Contribution No. 6023.

IMAGE PROCESSING

A COMPUTER MODEL FOR PREDICTION OF UNDERWATER IMAGES

Jules S. Jaffe, Stewart E. Harris
and Robert Squires

As part of a continuing effort to develop effective tools for deep ocean exploration, the Deep Submergence Laboratory (DSL) at the Woods Hole Oceanographic Institution has developed a computer model to simulate underwater image formation. The predictions of the model are in good qualitative agreement with the data collected from the first ARGO field operation

in the summer of 1984. Computer modeling of underwater images can be used as a computer aided design (CAD) tool in that the simulation of underwater imaging configurations will give the engineer valuable information about the performance of a given imaging system. This paper describes the model briefly.

In press: Proceedings from ROV Conference, San Diego, CA, April, 1985.

Supported by: Pew Foundation.

WHOI Contribution No. 5869.

I N S T R U M E N T A T I O N

THE ALVIN UPSTREAM COLLECTOR

John J. Akens

The ALVIN Upstream Collector, a component of the ALVIN Discrete Data System, is a general purpose 9 channel frequency counter interfaced to the ALVIN Data Stream. The ALVIN Discrete Data System is a subset of the ALVIN Data System which in turn is a subset of the ALVIN/ATLANTIS II Data System. This paper describes both of these major systems briefly and provides detailed coverage of the Upstream Collector hardware and software. Installation and operation instructions are included, and typical interfaces for the ALVIN high and low temperature measurement instruments and the ALVIN heat flow instruments are given. Details are also provided for interfacing a Neil Brown CTD.

Supported by: NSF Grant OCE83-20508.

WHOI Technical Memorandum No. 1-85,
Feb. 85.

IMPROVEMENT OF INTERMEDIATE OCEANOGRAPHIC WINCHES

H. O. Berteaux, R. G. Walden, L. W. Bonde
and J. D. Bird

The following is a report on the findings of a study conducted by the Woods Hole Oceanographic Institution to assess the needs and the means for improving the conventional intermediate winches used in the oceanographic community to lower profiling instruments (CTD for example).

Eight major U.S. oceanographic centers were visited to confirm community needs

and common problem areas and to survey existing lowering equipment and techniques. This information was used to develop a set of general requirements for an improved instrument lowering system. Recommended improvements included: compensation of wave induced ship motion, automation of casts, and capability for automatic tracking of oceanographic parameters.

A review is presented of additions or modifications which could meet these requirements. These options are compared and the system which offers the best potential for scientific usefulness, ease of fleet implementation and/or retrofitting of existing equipment is described at the conceptual and general specifications level.

A plan for the design procurement, test, and demonstration of a working prototype concludes the study.

Supported by: ONR Contract N00014-82-C-0019.

WHOI Technical Report No. 85-11.

SINGLE SHIP LARGE OFFSET SEISMIC PROFILING USING A SURFACE TOWED RADIO TELEMETRY ARRAY (STRATA)*

H. O. Berteaux, G. M. Purdy and W. Witzell

The precise measurement of the seismic velocities of the shallow crust in the deep (greater than 3 km) ocean requires source-receiver offsets (5-10 km) that are typically larger than that available from conventional multichannel hydrophone arrays (i.e., 2.4-3.6 km). Almost all our knowledge of the seismic structure of the deep ocean crust has been provided by experiments carried out at discrete locations, using sonobuoys or ocean bottom instruments. The result is that the available spatial sampling is too poor to reliably define possible systematic trends in the evolution of crustal velocities. This has stimulated our development and evaluation of a prototype surface towed radio telemetry array (STRATA) that can be towed at ranges up to 8 km astern of a research vessel underway, thus allowing the continuous estimation of velocities of the shallow basaltic basement (Figure 1).

Supported by: ONR Contract N00014-82-C-0019.

WHOI Contribution No. 6003.

A FREE OCEAN VEHICLE
TO MEASURE OPTICAL MICROSTRUCTURE.

Christopher H. Converse,
Albert J. Williams 3rd, Paul D. Fucile
and Raymond W. Schmitt

Processes of oceanic mixing are evident by the structure of interfaces between fluids of differing temperature and salinity. These generally produce index of refraction anomalies that can be imaged optically by the shadowgraph technique. We constructed a free-sinking instrument with a laser source, CCD video camera, and 8mm video cassette recorder that was deployed in a thermohaline staircase east of Barbados in November 1985. Stiffness and light weight were achieved with graphite fiber massive prisms. The instrument was designed to be mounted on the nose of a vertical fine and microstructure profiler but was deployed alone as a free vehicle. Images, time, and temperature were merged on the video tape and revealed turbulence at thermal interfaces.

Supported by: NSF Grant OCE84-09323.

WHOI Contribution No. 6096.

THE VAX GENERATION: MANAGEMENT DECISIONS

Robert C. Groman

The explosion of personal computers has had an impact on corporate decision making much beyond offering word processing, spreadsheet, and database capabilities to a large group of new computer users. It has focused attention on how computers are used, how to provide computer expertise to the end user, and whether the central computer site concept (time sharing) is viable in an age when hardware costs have dropped to the point of providing 32-bit CPUs and 20 megabyte Winchester disk drives to middle and upper management employees. This in turn raises new questions about intercomputer communications and networking and whether distributing powerful systems throughout an organization can be effectively supported.

This paper reviews the impact of the VAX computer and VAX/VMS at the Woods Hole Oceanographic Institution over the past six years and discusses such issues as: a) funding support for central computing facilities, b) the acquisition of more than 230 personal computers by scientific, technical, and administrative staff, and c) the availability of VAX-11/780-like speeds in UNIXbased, moderately-priced desktop computers.

Supported by: WHOI.

WHOI Contribution No. 5854.

CHEMISTRY OF SUBMARINE HYDROTHERMAL
SOLUTIONS AT 21°N, EAST PACIFIC RISE

K. L. Von Damm, J. M. Edmond, B. Grant,
C. I. Measures, B. Walden and R. F. Weiss

The three hydrothermal fields at 21°N latitude, East Pacific Rise, were resampled and an additional one was discovered. Maximum fluid temperatures observed were within a few degrees of 350°C and these waters had concentrations of Mg and sulfate indistinguishable from zero. One field, NGS, which had active 350°C springs in 1979, was inactive when first located in 1981. However, when a chimney was broken open during sampling, water issued at 273°C and continued to flow for at least five days. The chemical composition strongly suggests that these waters cooled conductively from 350°C in the sealed conduit.

The major ion data are consistent with the estimates based on extrapolation of the original measurements made on the hot springs from the Galapagos Spreading Center (Edmond et al., 1979a). The fluids have a pH of 3.5 and the sulfide-forming element concentrations show significant inter-field variations. Fe levels range from 0.8 to 2.4 mmol/kg; the ratio Fe:Mn varies from 0.9 to 2.9 similar to metal-liferous sediments on the ridge flanks, but much higher than observed at Galapagos (where sub-surface precipitation of iron sulfides occurs), indicating that the overwhelming proportion of the mass flux from hydrothermal systems occurs at high temperatures. Zn ranges from 40 to 106 μ mol/kg with Cu being substantially lower. Since the ratio of these elements in tholeiites is about unity, there is strong net preferential mobilization of Zn. Lead ranges from 183 to 359 nmol/kg. Nickel and Be are highly immobile relative to the other trace elements. The abundance of H₂S is about three times that of the total sulfide-forming cations. These data demonstrate that acid solutions at elevated temperatures can transport substantial amounts of ore-forming elements in the presence of large excesses of sulfide.

Published by: Geochimica et
Cosmochimica Acta, 49, 2197-2220,
1985. Printed in USA.

Supported by: NSF Grant OCE-8024057
(MIT).

ACOUSTIC ARRAY SENSOR TRACKING SYSTEM

Keith von der Heydt, Gregory L. Duckworth
and Arthur B. Baggeroer

Multichannel acoustic and geophysical experiments have been conducted recently in the Marginal Ice Zone (MIZ) of the eastern Arctic Fram Straits region using a random array of hydrophones deployed from ice floes with radio linked telemetry across apertures of up to 6 km. Accurate relative positions of hydrophone sensors in the array are required for subsequent data processing. A system of hardware and software has been developed to compute and record relative sensor positions and make plots of the sensor field in real time. Off-line processing uses sound speed profile corrections and model based filtering for greatest accuracy. The system consists of 5 reference sensors in the array field, each co-located with a hydrophone, emitting 5 millisecond tone bursts at a unique frequency approximately every 15 seconds. Signals are telemetered via a radio link to a receiving station where hardware detects pings and computes time delays between all sensors. These delays are acquired every 30 seconds, to compute an approximate set of array element locations and recorded for later processing. Relative location accuracies of 1 m rms can be obtained at ranges up to 5 km.

Supported by: ONR Contract N00014-81-C-0161.

NEW DEVELOPMENTS IN THE MOCNESS, AN APPARATUS FOR SAMPLING ZOOPLANKTON AND MICRONEKTON

P. H. Wiebe, A. W. Morton, A. M. Bradley,
R. H. Backus, J. E. Craddock, V. Barber,
T. J. Cowles and G. R. Flierl

Four variants of the Multiple Opening/Closing Net and Environmental Sensing System (MOCNESS) have been constructed to sample a broad size spectrum of oceanic animals from microzooplankton to micro-nekton. The systems differ in mouth opening dimensions (ranging from 1/4 to 20 m²), the number of nets carried (from 5 to 20), and the mesh size of the netting (from 64 m to 3.0 mm). A new electronics package enables an operator to send commands down a single conductor, armored cable to open/close the nets and provides 12-bit resolution for the environmental (temperature, depth, conductivity) and net operation data (flow, net-frame angle, net-bar release), which are transmitted up the cable to the deck unit at 2-s intervals. A microcomputer system, interfaced

to the deck unit, calculates salinity, volume filtered by a net, net trajectory velocity, and vertical velocity. The data are printed out and stored on disk, and profiles of temperature and salinity versus depth are plotted during the course of the tow. Analysis of the relationship between the geometry of the MOCNESS under tow and the past and present methods used to estimate the water filtered by a net revealed that significant bias is introduced when the ascent or descent angle of a net is disregarded. The bias is a function of the ratio of vertical velocity to net trajectory velocity and results in an underestimate of volume filtered while shooting a net and an overestimate while hauling.

Supported by: NSF Grant OCE80-17248.

WHOI Contribution No. 5856.

OCEAN ACOUSTICS

TOMOGRAPHIC MAPS OF THE OCEAN MESOSCALE. PART 1: PURE ACOUSTICS

B. Cornuelle, C. Wunsch, D. Behringer,
T. Birdsall, M. Brown, R. Heinmiller,
R. Knox, K. Metzger, W. Munk,
J. Spiesberger, R. Spindel, D. Webb
and P. Worcester

A field test of ocean acoustic tomography was conducted in 1981 for a two month period in a 300 km square at 26°N, 70°W in the North Atlantic (just south of the MODE region). Nine acoustic deep-sea moorings with sea floor transponders for automated position-keeping and with provisions for precise time-keeping were set and recovered. From the measured travel times between moorings, various displays of the three-dimensional field of sound speed (closely related to temperature) have been obtained by inversion procedures. These procedures use historical ocean data as a reference, but all information from the in situ surveys has been withheld; the "pure" tomographic results were then compared to direct in situ observations. The tomographically derived spatial mean profile compares favorably to an equivalent profile from the in situ observations; both differ significantly from the historical average. Maps constructed at three-day intervals for a two month period show a pattern of eddy structure in agreement with the direct observations within computed mapping errors, but these mapping errors are too large for

many oceanographic purposes. The mapping errors are the result of an unexpectedly large noise variance in travel time. (A 1983 experiment, using sources with larger bandwidth, reduced this variance to acceptable limits.) The 1981 tomographic results strongly suggest that the ocean sometimes undergoes transitions too rapid to be mapped over such large areas by shipboard observations.

Published in: Journal of Physical Oceanography, 15, 133-152, 1985.

Supported by: NSF Grant OCE82-14895.

W.H.O.I. Contribution 5961.

ACOUSTIC MODE PROPAGATION IN A RANGE DEPENDENT OCEAN

Yves Desaubies, Ching-Sang Chiu
and James Miller

Analytical approximate solutions obtained for acoustic mode propagation in a slowly varying ocean waveguide are discussed. Specific calculations are given for the particular case of propagation through mesoscale eddies in the western North Atlantic. An asymptotic expansion of the solution gives explicit expressions for the correction terms to the adiabatic approximation which is discussed in detail. It is found to depend strongly on acoustic frequency, mode number, and propagation range, and is applicable only for relatively low frequency and low mode number.

Supported by: ONR Contract N00014-82-C-0019.

W.H.O.I. Contribution No. 5890.

GEOACOUSTIC MODELS FOR THE ICELANDIC BASIN

George V. Frisk, Earl E. Hays
and James A. Douth

Geoacoustic models inferred from amplitude versus range data at 220 Hz are presented for three locations in the Icelandic Basin. The data were obtained using a deep-towed, pulsed CW source and two receivers anchored near the bottom. For ranges out to 4800 m, the data are analyzed using an iteration of forward models technique in which the parabolic equation method and a Hankel transform method are used sequentially to compute acoustic fields for different bottom parameters until best fits to the data are obtained. The inferred geoacoustic models

consist of a sediment layer containing a positive, linear sound speed gradient overlying an isovelocity subbottom. The geoacoustic parameters include the layer thickness, the sound speed gradient, and the sound speed discontinuities at the waterbottom and subbottom interfaces. The density and attenuation of the structures are also determined. The geoacoustic models are substantiated by other types of measurements, which include piston coring, 3.5 kHz seismic profiling, and in situ sediment profiling. These additional measurements, combined with the 220 Hz results, yield a consistent picture of the geoacoustic nature of the three areas. Specifically, the highly coherent character of the 220 Hz data, the clearly visible subbottom layering in the 3.5 kHz records, and the low values of attenuation are related to the fine-grained nature of the sediment at two of the sites. At the third site, the presence of coarse sediment provides an explanation for the major incoherent component in the 220 Hz data, the poorly discernible layering in the 3.5 kHz records, and an anomalously high value of attenuation.

Supported by: Johns Hopkins Applied Physics Laboratory Contract 601361-01 and ONR Contract N00014-82-C-0152.

WHOI Contribution No. 5835.

ANTISUBMARINE WARFARE

Robert C. Spindel

The security of our nation and the balance of world power depend on the submarine. Long an important part of naval warfare, the submarine's modern role is unprecedented. Fast, deep-diving, nuclear attack submarines (SSNs) form the major offensive unit of the Soviet Navy, and in the U.S. Navy serve to defend the carrier battle group, the basic unit of U.S. sea-power.

The nuclear ballistic missile carrying submarine (SSBN) is a mobile, covert, almost invulnerable launch pad for long-range missiles. Because the submarine is so crucial to national security, many of its activities are necessarily kept secret, making it difficult to assess its ultimate importance. However, the United States and the Soviet Union are devoting impressive financial and technical resources to submarine technology and to the expansion of their submarine forces.

Both nations consider the submarine to be an essential element in their military arsenals; it is a major sticking point in

arms-limitation negotiations. At the present time, the Soviet Union has approximately 375 submarines in service, about half of which are nuclear powered. The United States has a force of about 120, all nuclear powered. Both nations continue to build new, larger, more lethal submarines and submarine launched weapons.

Not so widely appreciated are the equally vigorous and expensive anti-submarine warfare (ASW) programs aimed at neutralizing the opponent's submarines. Nations with substantial naval forces, and those whose livelihoods depend on free access to the oceans, have large ASW research, development, and procurement programs, as well as vigilant ASW defenses. By far the greatest efforts are those of the United States and the Soviet Union, although there are significant activities in other countries, including England, Canada, France, Norway, Sweden, Australia, New Zealand, Japan, Italy, and West Germany. The North Atlantic Treaty Organization (NATO) staffs a laboratory in La Spezia, Italy, that has an ASW mission. The level of ASW activity in other free-world nations, such as Spain, the Netherlands, and Israel, is small, but not insignificant.

In the United States, ASW expenditures amount to more than \$12 billion annually, about 15 percent of the Navy's total budget. There is no reason to assume that the Soviet Union devotes fewer resources to this military category.

Published in: Oceanus, 28, 2,
Summer 1985.

Supported by: ONR Contract N00014-
84-C-0278 and NSF Contract OCE82-
14895.

ARCTIC ACOUSTIC TOMOGRAPHY MIZEX 84

Robert C. Spindel

This is the final report of Contract N00014-84-C-0185 between the Woods Hole Oceanographic Institution and the Office of Naval Research for the contract period 1 January, 1984, to 28 February, 1985. This contract supported an experiment that was conducted in the Norwegian Sea during May and June of 1984 to assess the possibilities of using ocean acoustic tomography as a measuring tool in the Arctic. The object of the experiment was to identify and determine the temporal stability (coherence) and resolvability of Arctic acoustic paths. Identification refers to the ability to match a pulse arrival with a particular ray path, primarily through

computer modeling. Resolvable rays are those that arrive sufficiently far apart in time so as to be distinct and separable. In order to use tomography, rays must be identified, resolved, and stable. Unlike the deep temperate ocean, where there are many wholly refracted paths, the upward refracting Arctic sound speed profile causes ray paths to reflect off the ice-covered surface of the permanent pack and the mixed ice-covered and ice-free surface of the marginal ice zones. The reflection process is time-varying and hence leads to resolvability, identification, and stability questions that do not arise in the case of entirely refracted paths.

A 224 Hz acoustic source was moored in an ice-free region. It transmitted phase coded, frequency stable signals to receivers fixed on the bottom and receivers drifting with the icepack at ranges of approximately 150 km. The received signals are to be analyzed with respect to identification, resolvability, and stability issues.

This contract covered the costs associated with installation and retrieval of the source and preliminary data reduction from the drifting and fixed hydrophones. Detailed data analysis costs are to be covered elsewhere. Nevertheless, preliminary analysis indicates that the received signals, particularly those from paths that interact with the ice-free surface, appear to have sufficient stability for tomographic purposes.

Supported by: ONR Contract N00014-
84-C-0185.

WHOI Technical Report 85-15.

OCEAN ACOUSTIC TOMOGRAPHY: A REVIEW

Robert C. Spindel

Ocean acoustic tomography is a technique for observing the dynamic behavior of ocean processes by measuring the changes in travel time of acoustic signals transmitted over a number of ocean paths. The travel time varies in proportion to the magnitude of the sound speed and current inhomogeneities along each path. The latter quantities can be estimated using mathematical inverse methods. A group of researchers have been developing this idea into a practical measurement tool. In this paper we review the basis for tomography, its implementation in several pilot experiments, and some current programs. We point out the limitations of present equipment and techniques and suggest areas for further development.

Supported by: ONR Contract N00014-84-C-0278 and NSF Grant OCE82-14895.

WHOI Contribution No. 6057.

RECIPROCAL ACOUSTIC TRANSMISSIONS: INSTRUMENTATION FOR MESOSCALE MONITORING OF OCEAN CURRENTS

P. F. Worcester, R. C. Spindel
and B. M. Howe

By simultaneously transmitting acoustic pulses in opposite directions between two points in midocean, one can separate the effects of ocean currents on acoustic propagation from the effects of sound-speed structure. Reciprocal acoustic transmissions can therefore be used to measure ocean currents. Acoustic transceivers have been designed and built to measure the mean currents between two points separated by 300 km. The equipment functioned satisfactorily during a short test conducted during 1983. Preliminary analysis of that experiment has yielded differential travel times that appear reasonable, but more work is required to relate the differential travel times to meaningful ocean-current estimates.

Published in: IEEE Journal of Oceanic Engineering, OE-10, 2, April 1985.

Supported by: ONR Contract N00014-84-C-0278 and NSF Grant OCE82-14895.

WHOI Contribution No. 5769.

U N D E R W A T E R R O B O T I C S

DEMONSTRATION OF CLOSED-LOOP TRAJECTORY CONTROL OF AN UNDERWATER VEHICLE

Dana R. Yoerger and James B. Newman

The design of the closed-loop control system is a primary issue for any underwater vehicle that is not controlled manually. Precise control of all vehicle movements is particularly difficult due to the high-order, nonlinear, uncertain nature of the dynamics of underwater systems. A new control system design methodology called sliding control has been shown to deal with these difficult problems effectively. In this paper, the methodology is reviewed and the results from in-water tests are described.

Published in: OCEANS '85, IEEE and MTS, San Diego, CA, 1985.

Supported by: ONR Contracts N00014-82-C-0743 and N00014-84-K-0070.

WHOI Contribution No. 6130.

ROBUST TRAJECTORY CONTROL OF UNDERWATER VEHICLES

Dana R. Yoerger
and Jean-Jacques E. Slotine

Underwater vehicles present difficult control system design problems due to their nonlinear dynamics, uncertain models, and the presence of disturbances that are difficult to measure or estimate. In this paper, a recent extension of sliding mode control is shown to handle these problems effectively. The method deals directly with nonlinearities, is highly robust to imprecise models, explicitly accounts for the presence of high frequency unmodelled dynamics, and produces designs that are easy to understand. Using a nonlinear vehicle simulation, the relationship between model uncertainty and performance is examined. The results show that adequate controllers can be designed using simple nonlinear models, but that performance improves as model uncertainty is decreased and that the improvements can be predicted quantitatively.

Published in: Journal of Oceanic Engineering, OE-10, 4, October 1985.

Supported by: ONR Contracts N00014-82-C-0743 and N00014-84-K-0070.

WHOI Contribution No. 5802.

U N D E R W A T E R S U R V E Y S

HOW WE FOUND TITANIC

Robert D. Ballard

A U.S.-French scientific expedition used high technology to locate the wrecked liner two and a half miles down in the North Atlantic and record unforgettable images.

Published in: National Geographic, 168, 6, December 1985.

Supported by: ONR Contract N00014-
82-C-0743.

THE GEOLOGICAL FORM AND SETTING OF A
HYDROTHERMAL VENTFIELD AT 10 56'N, EAST
PACIFIC RISE: A DETAILED STUDY USING
ANGUS AND ALVIN

T. F. McConachy, R. D. Ballard,
M. J. Mottl and R. P. Von Herzen

A hydrothermal ventfield occurs on the eastern marginal high near the edge of a narrow (95m) and shallow (15-20m) axial graben, within an area dominated by sheet flows and collapse features. The sheet flows are intermediate in relative age between young fluid flow lavas on the floor of the axial graben and older pillow (constructional) lavas on the marginal highs. Hydrothermal activity occurs in two zones within a 65m by 45m area. The main zone is located where a fissure system and sulfide-sulfate chimneys vent warm (9-47°C) and hot (347°C) hydrothermal fluids. Here, two mounds of massive sulfide are forming. One occurs at the base of a 3m high scarp which is the wall of a drained lava lake; the other is perched on top of the scarp, immediately to the east.

As the ventfield is located outside the axial graben, it is in a different setting from the majority of ventfields described by Hekinian et al. (1983b,c) at 13°N. However, it is still proximal to the neovolcanic zone and should share common plumbing systems with other hydrothermal deposits that are probably present in the axial graben at this latitude.

Supported by: NSF Grants OCE83-10175
and OCE83-09977.

DEPARTMENT OF PHYSICAL OCEANOGRAPHY
Robert C. Beardsley, Department Chairman

COASTAL CIRCULATION
AND DYNAMICS

SCATTERING OF LONG COASTAL-TRAPPED WAVES
DUE TO BOTTOM IRREGULARITIES

Kenneth H. Brink

The topographic scattering of long coastal-trapped waves is considered to see whether or not stratification tends to weaken scattering. Numerical examples show that this is not the case in general. Rather, susceptibility to scattering depends upon the particular example: in some cases it weakens with stratification, and in others it strengthens.

In press: Dynamics of Atmospheres and Oceans.

Supported by: NSF Grant OCE82-13968.

WHOI Contribution No. 5862.

TOPOGRAPHIC DRAG DUE TO BAROTROPIC FLOW
OVER THE CONTINENTAL SHELF AND SLOPE

Kenneth H. Brink

A barotropic model is formulated to investigate the topographic drag due to steady barotropic alongshore flow over the continental shelf and slope. The topography is extensive, irregular, and of small amplitude. Topographic drag is, in general, only appreciable when the mean flow runs counter to the direction of free shelf wave phase propagation. The cross-shelf structure of the drag is determined by which mode lee waves dominate. This selection is determined by the projection of the topographic structure onto the wave mode and by the degree of matching between topographic length scale and natural lee wave wavelength.

Supported by: NSF Grant OCE84-08563.

WHOI Contribution No. 6016.

CIRCULATION IN THE POINT CONCEPTION-
SANTA BARBARA CHANNEL REGION

Kenneth H. Brink and Robin D. Muench

During spring and early summer 1983, fifteen current moorings were deployed around the periphery of Santa Barbara Channel and over the continental shelf to the west, off Point Conception. Data from

these moorings have been used to describe the regional circulation and to address problems of wind forcing and the spatial coherency scales for current fluctuations. The mean circulation in Santa Barbara Channel was dominated by a westward jet which occupied the northwestern portion of the Channel. Current and temperature fluctuations were generally well correlated among all locations around the Channel, and time lags suggested cyclonic propagation of events around the Channel. The time fluctuations were dominated by a relatively few low-frequency events. It was impossible to determine exactly either the driving mechanisms for these events or their relationships to regional flow. The flow regime was considerably different off Point Conception than in the Channel. Locally wind-driven upwelling was observed in both the mean and fluctuating flows, and the time scales of current variability (i.e., spectral shapes) mimicked those of the local winds. A dramatic change in the regime off Point Conception occurred in late May. Before the transition, currents and sea levels had been well correlated in time with both local and remote winds. After late May the relation to fluctuating winds was less clear and the alongshore structure of sea level variability had changed radically.

Published in: Journal of Geophysical Research, 91, 877-895.

Supported by: NSF Grant OCE82-13968.

WHOI Contribution No. 5949.

A SIMPLE MODEL OF THE FORMATION AND
MAINTENANCE OF THE SHELF/SLOPE FRONT
IN THE MIDDLE ATLANTIC BIGHT

David C. Chapman

The strong salinity and temperature gradients across the shelf/slope front in the Middle Atlantic Bight often compensate such that the cross-front density gradient is nearly eliminated. This suggests that the density field may not be as dynamically important as has been assumed in previous models. Hypothesizing this to be the case, a simple steady barotropic model, which allows no density variations, is used to demonstrate that a strong tracer gradient may form near the shelf break. The velocity field is such that an initially smooth tracer distribution develops a sharp front within a relatively short downstream distance. Essential features of the model are the velocity convergence near the shelf break which acts to sharpen the front on the shelf side, and the sudden increase in

bottom slope at the shelf break which inhibits the diffusion of tracer into the deep ocean. The result is that the front is maintained for a large alongshelf distance against both diffusion and the frictional decay of the alongshelf velocity.

In press: Journal of Physical Oceanography.

Supported by: NSF Grant OCE84-17769.

WHOI Contribution No. 6080.

ON THE CONTINUITY OF MEAN FLOW
BETWEEN THE SCOTIAN SHELF
AND THE MIDDLE ATLANTIC BIGHT

David C. Chapman, John A. Barth, Robert C. Beardsley and Richard G. Fairbanks

Oxygen-isotope tracer data combined with results from two linear barotropic coastal models are used to argue that the observed equatorward mean alongshelf flow in the Middle Atlantic Bight is a downstream extension of the mean alongshelf flow over the Scotian Shelf. Qualitative agreement between model results and observations supports the concept that the alongshelf pressure gradient associated with the mean alongshelf flow in the Middle Atlantic Bight has an upstream or downstream and not an offshelf origin. The role of the local large-scale general circulation is apparently to help keep the shelf water on the shelf rather than to drive the shelf mean flow.

In press: Journal of Physical Oceanography.

Supported by: NSF Grants OCE80-14941 and OCE82-13968.

WHOI Contribution No. 5877.

ASSESSING HAZARDS DUE TO CONTAMINANT
DISCHARGE IN COASTAL WATERS

James H. Churchill

Models of contaminant dispersion in the marine environment have mostly sought to determine the mean concentration field. At a location not far from a pollution source, concentration is intermittently high, depending on whether the site is immersed in the concentrated contaminant plume which emanates from the source. At such a locale the probability of immersion, denoted by visitation frequency, is a more meaningful measure of nuisance than mean concentration. Three methods of computing

visitation frequency from moored current meter data, each having particular advantages and drawbacks, are presented. These are applied to the coastal region off Long Island, New York, where a definite seasonal character of the visitation frequency field is revealed.

Supported by: DoE Contract DE-AC02-79EV10005.

WHOI Contribution No. 6011.

MEAN CURRENTS DRIVEN BY TOPOGRAPHIC DRAG
OVER THE CONTINENTAL SHELF AND SLOPE

Dale B. Haidvogel and Kenneth H. Brink

A sequence of numerical simulations is described of wind-driven flow over irregular continental shelf topography. The model is barotropic, non-linear, and forced by a periodic, spatially uniform alongshelf wind stress. The objective of the study is to determine whether topographic drag, known to be asymmetric for barotropic flow over the shelf (Brink, "Topographic drag due to barotropic flow over the continental shelf and slope," submitted for publication in 1985 to J. Phys. Oceanogr.), can generate substantial time-averaged alongshore currents even in the presence of a fluctuating zero-mean wind stress.

With realistic parameters, mean maximum alongshore currents of 0.05 to 7.0 cm/sec are realized with flow in the direction of freely propagating shelf waves. The residual current strength is a strong function of wind stress period and bottom bump wavelength; larger forcing periods and shorter bump wavelengths enhance the time-mean circulation. Model simulations using realistic spectra for both wind stress and bottom roughness yield a maximum flow of approximately 2.5 cm/sec. These results demonstrate that topographic drag asymmetries can lead to observable mean currents on continental shelves and may be a partial explanation for certain observed mean currents that run counter to mean alongshore winds.

Supported by: NSF Grant OCE84-08563 and NSF to the National Center for Atmospheric Research.

WHOI Contribution No. 6119.

WESTWARD INTENSIFICATION OF THE MEAN
CIRCULATION ON THE BERING SEA SHELF

Thomas H. Kinder, David C. Chapman and John A. Whitehead, Jr.

Most of the water that eventually flows northward through Bering Strait originates about 500 km south, seaward of the shelf-break in the Bering Sea. Cumulative observational evidence supports the idea that most of this northward flow across the gently shoaling eastern Bering Sea continental shelf occurs as a western boundary current along the Siberian coast. A homogeneous rotating laboratory model and a barotropic numerical model each demonstrate this westward intensification of the mean flow. The intensification results from the well-known topographic β -effect: the combination of rotation and the depth decrease in the direction of flow acts in a similar fashion to the meridional gradient of the Coriolis parameter. For reasonable values of Bering Strait transport and shelf bottom friction, current speeds of 10-20 cm/sec and a current width of ~ 50 km are predicted.

In press: Journal of Physical Oceanography.

Supported by: NSF Grant OCE84-17769 and ONR Contract N00014-85-C-0001, NR 083-004.

WHOI Contribution No. 5994.

INTERANNUAL VARIABILITY OF COASTAL AND SLOPE WATER MASSES ALONG THE WESTERN NORTH ATLANTIC

Vincent D. Lyne and Charles N. Flagg

During the mid 60's, the upper few hundred meters of the Mid-Atlantic Bight slope water masses were anomalously cold and fresh. This period coincided with intensified air-sea interaction events that brought drought conditions to the Northeast American Continent and enhanced cold westerly winds blowing over the seaboard. Our analysis of the available meteorological and hydrographic evidence suggests that the anomalies are the result of enhanced production of "mixed slope water" in the slope waters of the Scotian Slope/Grand Banks region. Wintertime convection and cooling were intensified during this period and the surface temperatures at Boothbay Harbor declined to a long-term minimum. Speculative evidence is provided for increased meanderings of the Gulf Stream which may have contributed to the appearance of the anomalies.

Fresh salinity anomalies in the halostad and deeper slope water are inferred to be the result of alongshore advection and not local formation. The longevity of the deeper anomalies suggests that they are either coherent lenses or prevalent

throughout the slope water during this period.

Supported by: DoE Contract DE-AC02-79EV10005 and USGS & Mineral Management Services through Inter-agency Agreement 14-12-0001-30180.

WHOI Contribution No. 6039.

INSTRUMENTATION AND EXPERIMENTAL METHODOLOGY

A COMPARISON OF THE VACM AND NEW EG&G VMCM ON A SURFACE MOORING IN CODE-1

Robert C. Beardsley

An intercomparison experiment was conducted between a near-surface VACM (Vector-Averaging Current Meter) and an EG&G VMCM (Vector-Measuring Current Meter) at a mid-shelf mooring site ($38^{\circ}32.8'N$, $123^{\circ}22.6'W$) located in 90 m of water off northern California between April and July 1981. The VACM and VMCM were deployed at 9 and 11 m, respectively, beneath a 1.5 m spherical surface buoy on a slack mooring. The VACM and VMCM one-hour vector-averaged velocities were highly correlated with a complex correlation coefficient amplitude of .991, indicating the relative effectiveness of the internal vector-averaging sampling scheme of the VACM and the flow sensors of the VMCM to filter much of the wave-induced high frequency currents and mooring motion. The vector-averaged VACM speeds S_a generally exceeded the VMCM speeds S_m by up to 10 cm/sec. Since the observed difference in vector-averaged speeds, $\Delta S = S_a - S_m$, was larger on average than an independent estimate of the true shear by a factor of 4 to 5, most of the difference in the observed VACM and VMCM vector-averaged speeds has been attributed to instrumental error.

The surface wave climate was measured nearby over the shelf during part of the experiment and a significant correlation was found between estimates of the rms horizontal velocity and rms difference vertical velocity based on the observed wave data and a VACM-derived rms wave speed W defined as $\sqrt{R^2 - S_a^2}$, where R is the hourly-averaged VACM rotor speed. This result allows the fractional vector-averaged speed difference $\Delta S/S_m$ to be determined experimentally from the field data as a function of S_m/W , a signal-to-noise param-

eter expressing the ratio of the observed VMCM vector-averaged speed to the VACM-derived rms wave speed W . Although significant scatter occurs between simultaneous one-hour vector-averaged VACM and VMCM speeds, the average fractional speed difference $\Delta S/S_m$ decreases from about 0.57 ± 0.10 (at 95% confidence) at $S_m/W = 0.15$ to about 0.20 at $S_m/W = 1.0$ and remains approximately constant at 0.16 ± 0.02 for S_m/W between about 1.5 and 2.0. Thus the fractional speed difference observed in the field is a relatively well-defined function of the relative magnitudes of the mean horizontal and wave associated flow components.

Comparison of these field measurements with published laboratory data on the performance of the VACM and VMCM in unsteady flow suggests that the field and laboratory measurements are consistent and can be used to estimate the absolute fractional speed error of each current meter as a function of u/w , where u is the true mean horizontal vector speed and w the amplitude of the rms wave-induced oscillatory velocity. The combined laboratory and CODE-1 (Coastal Ocean Dynamics Experiment) field data thus indicate that, in an absolute sense, the VACM over-responds by about 18-20% at $u/w = 0.5$ to about 10-11% at $u/w = 2.0$ and the VMCM under-responds by about -5 to -6% for u/w between 0.5 to 2.0. These results should be independent of mooring type and thus allow estimation of absolute error in velocity measurements made with VACMs and VMCMs in the range of u/w between 0.5 and 2.0.

Supported by: NSF Grant OCE80-14941.

WHOI Contribution No. 6005.

AN EMPIRICAL EQUATION OF STATE FOR PURE WATER IN THE OCEANOGRAPHIC REGION OF TEMPERATURE AND PRESSURE DETERMINED FROM DIRECT MEASUREMENTS

Alvin L. Bradshaw and Karl E. Schleicher

Polynomial regression fits to the results of measurements on distilled water of the thermal expansion at a number of pressures and of the compression at a single temperature are combined to form an empirical equation of state which is valid in the ranges $T \leq 0$ to 30°C and atmospheric pressure to 1000 bars. The specific volume from the equation has a standard error of $3 \times 10^{-6} \text{ cm}^3/\text{g}$ or better over the entire region, and its inaccuracy is estimated to be not worse than $25 \times 10^{-6} \text{ cm}^3/\text{g}$ at 1000 bars. The measurements are direct volumetric ones which are based on calibrations using mercury P-V-T data. The

equation of state for water presented agrees within $20 \times 10^{-6} \text{ cm}^3/\text{g}$ with two recent equations derived from sound speed measurements. Some properties derived from the equation are compared with those found by others.

In press: Journal of Chemical and Engineering Data.

Supported by: NSF Grant OCE74-18158.

WHOI Contribution No. 5898.

A NOTE ON THE CORRECTION OF TEMPERATURE AND VELOCITY TIME SERIES FOR MOORING MOTION

Nelson G. Hogg

Several schemes for correcting temperature and velocity measurements from moored current meters are tested on two moorings, one of which experienced large vertical excursions as the Gulf Stream meandered over it. The addition of two extra temperature recorders 100 m above and below the current meter permits the calculation of a reference corrected series through time dependent interpolation. By assuming that the current meter profiles the vertical temperature structure as it is pulled up and down, it is possible to calculate the mean vertical temperature gradient and its dependence on temperature. A quadratic dependence is suggested by hydrographic measurements and the direct in situ measurements on the moorings. It is found possible, through weighted polynomial regression, to calculate this dependence directly from measurements of temperature and pressure on a single instrument and, thereby, to remove more than 95 percent of the mooring motion induced temperature variance. The correction of temperature for mooring motion is found necessary for accurate estimation of heat flux from moorings in energetic areas.

Correction of velocity is more difficult, but it is not found to have much effect on flux calculations.

In press: Journal of Atmospheric and Oceanic Technology.

Supported by: ONR Contract N00014-76-C-0197, NR 083-400 and NSF Grant OCE82-14925.

WHOI Contribution No. 5897.

BUOYANCY DRIVEN INSTABILITIES OF LOW
VISCOSITY ZONES AS MODELS OF
MAGMA-RICH ZONES

John A. Whitehead, Jr.

The low Reynolds number dynamics of a thin layer of fluid bounded below by a flat horizontal boundary and above by a fluid of another viscosity and greater density is reported. Three distinct stages of growth were observed. The first stage is a Rayleigh-Taylor instability, in which disturbances of one specific wavenumber grow most rapidly. If ϵ is the ratio of the viscosity of the thick layer to the viscosity of the thin layer, fastest growth is for wavenumber $\epsilon^{-1/3}$. In the second stage, distortion of the interface is large, and it is found experimentally that the fluid moves out of the thick layer as circular columns surrounded by relatively broad regions of descending material. In the third stage, fully matured structures are formed. If the upwelling material has less viscosity than the surrounding material, the structure develops a rim syncline and a pronounced overhang and eventually ascends as a spherical pocket of fluid fed by a conduit. Two applications to geophysics are given. The first application follows from the fact that a melt source must exist in the mantle below mid-ocean ridges. This source can be approximated as a cylindrical body with lower viscosity and density compared to the overlying mantle. If the cylinder develops a gravitational instability, it will develop regularly spaced vertical protrusions. Estimates of the spacing are compared to high resolution segmentation data, and some constraints on viscosity of the mantle below spreading centers are made. These are that viscosity of the mantle is 10^{18+1} poise, and the ratio of this viscosity to the viscosity of the cylinder is less than 100. In the second application, the upwelling conduits are measured experimentally and solitary waves are observed. A recently found analog with magma rising up through the pores of a viscous crystalline matrix is discussed.

In press: Partial Melting Phenomena in the Earth and Planetary Evolution, Journal of Geophysical Research, Special Issue.

Supported by: WHOI Center for Analysis of Marine Systems.

WHOI Contribution No. 5906.

FLOW OF A HOMOGENEOUS ROTATING FLUID
THROUGH STRAITS

John A. Whitehead, Jr.

A formulation is presented for barotropic, steady, inviscid flow through a rectangular opening by a rotating fluid. Magnitude of the flow depends on difference in free surface height $\Delta\zeta$, force of gravity g , Coriolis parameter f , and opening width w . It is not necessary for the channel to approach the Rossby Radius in width for important rotational effects to be felt. When $W/w < 1$ (the ratio of a novel width scale $W = (2g\Delta\zeta)^{1/2}/f$ to channel width), the Garrett and Toulany (J. Geophys. Res., 87, 1968-1978, 1982) prediction for mean velocity of $\bar{v} = g\Delta\zeta/fw$ is found. In the converse limit, $\bar{v} = (2g\Delta\zeta)^{1/2} - fw/2$. Both are confirmed by laboratory experiment. The laboratory flow approximately matches the assumption that relative vorticity is $-f$. There are straits in the oceans and flows through mountain passages which may be governed by the laws discussed here.

In press: Geophysical and Astrophysical Fluid Dynamics.

Supported by: ONR Contract N00014-85-C-0001, NR 083-004.

WHOI Contribution No. 6004.

LARGE SCALE OCEANIC
HEAT TRANSPORT AND
WATER PROPERTIES

WHAT CONTROLS THE RATE OF EQUATORIAL
WARM WATER MASS FORMATION?

Gabriel T. Csanady

Equatorially formed warm water must escape poleward. Yet, such water is of low density and of zero potential vorticity, so that its cross-latitude transfer is subject to inertial constraints. These constraints can act as a feedback mechanism controlling the escape, and hence the formation rate of equatorial warm water.

In the equatorial Atlantic, newly formed warm water flows westward and eventually forms the surface layer of the North Brazilian Coastal Current (NBCC). An inviscid, inertial model shows that the total northwestward transport of equatorial warm water is largely determined by a "northern" water mass of the same density as the in-

truding mass but of a substantially different (positive) potential vorticity, which effectively blocks the intrusion. The key control variable is the ratio of rest depths of the two water masses in contact.

For given potential vorticity of the northern water mass, warm water transport depends on the depth of the warm layer at the western boundary. For given wind stress, this depth also determines where the equatorial pycnocline becomes shallow enough to allow warm water mass formation. Deepening of the layer increases the escaping transport but reduces the formation rate: this negative feedback mechanism establishes an equilibrium rate of warm water mass formation and escape.

In the shallow mixed layer of the eastern North Atlantic, the principal momentum balance is between wind stress and vertical momentum advection from the Undercurrent. A simple model of this process yields a quantitative estimate of the equatorial upwelling rate per unit zonal length. Combination of this model with the NBCC model leads to an estimate of the total equatorial upwelling rate (order $10^7 \text{ m}^3 \text{ s}^{-1}$) and net oceanic heat adsorption in the equatorial Atlantic (order 10^{14} W).

Supported by: ONR Contract N00014-82-C-0019, NR 083-004.

WHOI Contribution No. 6040.

HYDROGRAPHIC SECTIONS IN THE KUROSHIO EXTENSION AT 165°E AND 175°W

Terrence M. Joyce

Two meridional XBT and CTD/ O_2 sections were occupied across the Kuroshio extension in the autumn of 1983 on the longitudes of 165°E and 175°W on the R/V THOMPSON. The western section spanned the latitudes 30°30'N-43°N and was east of the Shatsky Rise and west of the Emperor Seamount chain. The eastern section was to the east of the Hess Rise between 28°N and 42°45'N latitudes. The baroclinic flow across 165°E was concentrated into two eastward jets 100 km wide which could be identified with the eastward extension of the Kuroshio and Oyashio (subarctic) fronts. The former had an eastward volume transport of 55 Sverdrups while the latter had an eastward transport of 19 Sv relative to the ocean bottom. These two narrow zones of flow were imbedded in a broader zone of weak, baroclinic volume transport to the west. To the east of the Emperor Seamounts, the meridional property gradients were substantially reduced. While the signatures of the Kuroshio and subarctic fronts were

still evident, the 175°W section was dominated by eddies with meridional scales of approximately 100-200 km. One of these eddies appeared to be a detached warm-core ring of Kuroshio water. To the south of 32°N, a broad zone of westward baroclinic flow reduced the net transport for the section to zero. Zonal gradients of dissolved oxygen at mid-depths and potential vorticity in the abyss, argue against direct flow pathways between the two sections. Salinity and oxygen variations in the oxygen minimum layer indicated a deep property front at 30°N on 175°W which may extend westward toward Japan as far as 152°E.

Supported by: ONR Contract N00014-82-C-0019, NR 083-004.

WHOI Contribution No. 5868.

ON THE GEOTHERMAL HEATING OF THE ABYSSAL SUBARCTIC PACIFIC OCEAN

Terrence M. Joyce, Bruce A. Warren and Lynne D. Talley

Recent deep CTD/ O_2 measurements in the abyssal North Pacific along 175°W, 152°W, and 47°N indicate that large-scale changes in the Θ/S characteristics exist in the deepest kilometer of the water column. These variations can be rationalized by invoking geothermal heat flux from the abyssal sediments as the agent for causing large-scale modification of abyssal temperatures (but not salinities) in the subarctic Pacific Ocean. East-west and north-south thermal age differences of about 100 years are inferred using a spatially uniform geothermal heat flux of $5 \times 10^{-2} \text{ W/m}^2$.

Supported by: NSF Grants OCE84-16197 & OCE84-16211 and ONR Contracts N00014-82-C-0019, NR 083-004 & N00014-84-C-0278, NR 083-004.

WHOI Contribution No. 6109.

OCEAN CIRCULATION

LATE QUATERNARY DEEP-OCEAN CIRCULATION

Bruce H. Corliss, Douglas G. Martinson and Thomas Keffer

A review of paleoceanographic studies dealing with late Quaternary deep-water circulation in the oceans is presented. These studies, which are based on the anal-

ysis of deep-sea benthic foraminiferal faunal and geochemical data and sedimentological data, are discussed in light of physical oceanographic conditions in the modern ocean.

Supported by: the Center for Analysis of Marine Systems, WHOI, and NSF Grant DPP82-16539.

WHOI Contribution No. 6117.

HORIZONTAL AND VERTICAL STRUCTURE OF THE GULF STREAM VELOCITY FIELD AT 68°W

Melinda M. Hall

A current meter mooring, instrumented from the bottom into the thermocline, was deployed in the Gulf Stream at 68°W for a year. Data from the uppermost instrument indicate the Gulf Stream moved back and forth across the mooring site, so that the horizontal as well as vertical structure of the Stream may be deduced. The two key points to the success of the analysis are: (1) the well-defined relationship between temperature and cross-stream distance in the thermocline, enabling the use of the former as a horizontal coordinate; and (2) a daily-changing definition of Gulf Stream flow direction based on the shear between the thermocline and 2000 m depth. Time-series of daily-rotated velocities may be used to calculate empirical orthogonal functions for the along- and cross-stream vertical structures, which are decoupled and are respectively baroclinic and barotropic. Using the inferred horizontal coordinate, one can estimate mass, momentum, and kinetic energy fluxes for four individual events when the entire Stream swept by the mooring. The results for mass fluxes agree well with historical data. Bryden's (J. Geophys. Res., 85, 2825-2828, 1980) method has been used to calculate vertical velocities from the temperature equation; the resulting time-series of w are visually coherent throughout the water column and their vertical amplitude structure looks like that of a first baroclinic mode. The rms vertical velocities are large [$0(.05 \text{ cm s}^{-1})$], and these as well as other estimates have been used to explore the validity of the quasi-geostrophic approximation at the mooring site. The Rossby number for the thermocline flow is about 0.3 and for the deep flow is ≤ 0.1 .

Supported by: NSF Graduate Fellowship Grants OCE82-08746 and OCE85-00598 and ONR Contract N00014-82-C-0019, NR 083-004.

WHOI Contribution No. 6038.

ZONAL PENETRATION SCALE OF MODEL MIDLATITUDE JETS

William R. Holland
and William J. Schmitz, Jr.

All available observations indicate that the most energetic time-dependent currents are located in the vicinity of intense large-scale oceanic current systems. This characteristic is also a basic property of eddy-resolving gyre-scale numerical models. An initial detailed intercomparison of two-layer, eddy-resolving numerical experiments with observation focused on the largest scales of horizontal structure in patterns of abyssal eddy kinetic energy and on time scales. The numerical experiments examined generally had relevant temporal and meridional scales, but not necessarily realistic zonal scales. The model eddy field did not penetrate as far from the western boundary as observed distributions, by a factor of 2 to 3.

The present study examines the physical processes that govern the model zonal penetration scale and suggests reasons for the previous discrepancy. It is demonstrated that a subtle balance exists between the complex instability processes that tend to tear the jet apart (restricting its zonal penetration) and the tendency for inertial processes to carry the intense current right across the basin. It would seem that any factor that changes the nature of the instability of the thin Gulf Stream jet will alter the penetration scale. In these models this means not only changing physical parameters and including different physics, but also changing such model dependent factors as vertical resolution. Earlier work suggested the need for enhanced vertical resolution to give realistic zonal penetration, but it is now clear that all stabilizing/destabilizing effects conspire together to give a particular penetration scale.

Published in: Journal of Physical Oceanography, 15, 1859-1875, 1985.

Supported by: ONR Contracts N00014-76-C-0197, NR 083-400 and N00014-84-C-0134, NR 083-400 and NSF to the National Center for Atmospheric Research.

WHOI Contribution No. 5903.

SYNOPTIC GULF STREAM VELOCITY PROFILES THROUGH SIMULTANEOUS INVERSION OF HYDROGRAPHIC AND ACOUSTIC DOPPLER DATA

Terrence M. Joyce, Carl I. Wunsch
and Stephen D. Pierce

Data from a shipborne acoustic profiling device have been combined with CTD/O₂ sections across the Gulf Stream to form estimates of the absolute flow fields. The procedure for the combination was a form of inverse method. The results suggest that at the time of the observations (June 1982) the net Gulf Stream transport across 72.5°W was 107±11 Sverdrups (subject to further uncertainty from the definition of the Stream). The transport of the Deep Western Boundary Current was 9±3 Sv. These and other transport estimates are plausibly close to previous calculations, but we do not claim they represent the temporal mean. For comparison purposes, we have done an inversion using the hydrographic/O₂ data alone as in previously published results and obtained qualitative agreement with the Doppler-calibrated inversion. Inversion of the acoustic measurements alone, when corrected for instrument biases, leaves unacceptably large mass transport residuals in the deep water. Our conclusion is that the inversion of the combined data sets produces results much improved over those from using either acoustic or hydrographic/chemical constraints in isolation. The procedures are close analogues to those which can be used with satellite altimeters and are a procedure for obtaining very accurate geoid slope measurements.

Supported by: NSF Grants OCE85-01176 and OCE80-18515 and NASA Grant NAG 5-534.

WHOI Contribution No. 6068.

A QUASI-SYNOPTIC SURVEY OF THE CIRCULATION AND WATER MASS DISTRIBUTION WITHIN THE CANARY BASIN

Rolf H. Käse, James F. Price,
Philip L. Richardson and Walter Zenk

Shipboard hydrographic measurements and moored current meters are used to infer both the large scale and mesoscale water mass distribution and features of the general circulation in the Canary Basin. We found a convoluted current system dominated by the time-dependent meandering of the eastward flowing Azores Current and the formation of mesoscale eddies. At mid-depths, several distinctly different water masses are identified: Subpolar Mode and Labrador Sea Water are centered in the northwest, Subantarctic Intermediate water is centered in the southeast, and the saltier, warmer Mediterranean tongue lies between them. Mesoscale structures of these water masses suggest the presence of mid-depth meanders and detached eddies

which may be caused by fluctuations of the Azores Current.

In press: Journal of Geophysical Research.

Supported by: Deutsche Forschungsgemeinschaft and NSF Grant OCE82-14066.

WHOI Contribution No. 6047.

EASTERN PACIFIC OCEAN CIRCULATION NEAR THE ONSET OF THE 1982/83 EL NIÑO

Linda J. Mangum, Stanley P. Hayes
and John M. Toole

Over a one month period during the initial stages of the 1982/83 El Niño, hydrographic measurements were made in the eastern equatorial Pacific by two research vessels. Water mass characteristics and apparent circulation along a 10° square centered near the Galapagos are discussed, in which large interannual changes in the current system were observed. Sea surface temperature nearly everywhere was warmer than 25°C; the thermocline was depressed to between 50 and 100 dbar. The 15°C isotherm extended below 100 dbars throughout the region, reaching a maximum depth of 245 m near the equator at 85°W. The Galapagos Front was not observed during this period. Dynamic height profiles and direct velocity measurements indicate significant eastward flow throughout the area resulting in the disappearance of the South Equatorial Current. Surface westward flow along 95°W was only observed in a narrow band north of 2°N. Uniform T-S properties of the waters north of the equator indicate that the probable source of this westward flowing water was a recirculation of an enhanced North Equatorial Countercurrent.

Supported by: NSF Grant OCE83-08415.

WHOI Contribution No. 5985.

MAPPING CLIMATOLOGICAL SEASONAL VARIATIONS OF SURFACE CURRENTS IN THE TROPICAL ATLANTIC USING SHIP DRIFTS

Philip L. Richardson and David Walsh

The seasonal variability of current velocities in the tropical Atlantic was studied by grouping ship drift velocity observations into 2° x 5° boxes and calculating monthly mean velocity values. These values were used to calculate and map the annual mean velocity, the seasonal variation about the mean, the annual and semi-

annual harmonics, and the first two Empirical Orthogonal Functions (EOFs).

The seasonal variation is primarily zonal in the equatorial band and in the North Equatorial Countercurrent (NECC) and primarily alongshore near the coast of South America. Maxima of seasonal variation of 23 cm/sec are centered in the NECC near 6°N, 42.5°W and in the Gulf of Guinea near 2°N, 7.5°W. Most (~80%) of the variance in the NECC and along the western boundary of the area studied has an annual period; most variance along the equator in the mid-Atlantic has a semiannual period.

The second EOF, which contains 29% of the variance, shows a contemporaneous speeding and slowing of the major equatorial currents -- the South Equatorial Current, the North Brazil Current, the NECC, and the Guinea Current -- with a simultaneous slowing and speeding of the Guyana Current and Brazil Current. The velocity pattern resembles a large equatorial gyre centered along 4°N that flows clockwise from May to September and counterclockwise most of the rest of the year. The first EOF contains 35% of the variance and shows a simultaneous speeding and slowing of eastward velocity from 5°S-10°N except for the western South Equatorial Current and Guinea Current. The pattern near the equator in the west is explained by the slowing and reversal of the South Equatorial Current near 2°N, 40°W during April-June. This slowing is part of the NECC start-up, which occurs before the NECC runs eastward across the Atlantic from July-December.

The South Equatorial Current, impinging on the coast of Brazil, divides seasonally in two places. The first is near the eastern tip of Brazil, where residual alongshore velocity is northward for half the year, peaking during May-June, and then is southward for the other half year. The second division is north of the Amazon, where the North Brazil Current continues up the coast during the first half of the year but partially retroreflects into the NECC during the last half of the year. A fast eastward flow in the NECC coincides with a faster than usual North Brazil Current and a slower than usual Guyana Current.

Supported by: NSF Grants OCE82-08744 and OCE82-17112.

WHOI Contribution No. 6069.

R I N G S, E D D I E S

A CYCLONIC EDDY AND SHELF/SLOPE WATER EXCHANGE ASSOCIATED WITH A GULF STREAM WARM-CORE RING

James H. Churchill, Peter C. Cornillon and George W. Milkowski

Warm-core ring (WCR) 83D passed through a linear array of moored temperature, conductivity and velocity sensors during October 1983. Satellite-derived thermal imagery combined with data from the moored sensors have revealed a cold-core cyclonic eddy of approximately 80 km diameter, traveling in advance of Ring 83D. This cyclone, whose angular momentum magnitude was about 1/3 that of the warm-core ring, evolved either during or shortly after the WCR's formation. Hydrographic and moored sensor data suggest that the WCR brought about a sub-surface exchange of shelf and slope water, with near-surface slope water moving onshore and near-bottom shelf water being drawn offshore and around the ring. Examination of 308 cross-shelf hydrographic sections from the Middle Atlantic Bight has indicated that such exchange commonly occurs in the presence of a WCR. This apparent ring-induced exchange may significantly affect the overall salt balance of Middle Atlantic Bight shelf water. As an example, the volume of slope water within a well-surveyed intrusion, which lies on-shelf of WCR 79B, was 16% of Wright's (J. Mar. Res., 34, 1-14, 1976) estimate of the annual slope water transport to the Middle Atlantic Bight shelf.

Supported by: DoE Contract DE-AC02-79EV10005 and ONR Contract N00014-81-C-0062.

WHOI Contribution No. 6118.

THE POLYMODE ATLAS

Vladimir M. Kamenkovich, Andrei S. Monin and Arthur D. Voorhis, editors

An atlas has been prepared for publication by the Woods Hole Oceanographic Institution which summarizes accomplishments and presents processed data from the large joint US/USSR oceanographic field program called POLYMODE. This program was carried out over the years 1974 through 1979 to study synoptic (or mesoscale) eddies in the western North Atlantic. Eighteen research vessels and scientists from more than ten institutions in the U.S., Canada, and the Soviet Union participated in the

field work. The atlas is bilingual (English/Russian) and is divided into four major sections: Statistical-Geographic Experiments, Synoptic Dynamic Experiment, Local-Dynamics Experiment, and an extensive Appendix. A large quantity of data is included on 42 microfiche sheets which accompany the atlas.

In press: Woods Hole Oceanographic Institution.

Supported by: NSF Grants OCE78-25612 and OCE84-44717.

WHOI Contribution No. 6077.

INTERCOMPARISONS OF THE ZONAL, VERTICAL AND TEMPORAL SCALES OF OBSERVED AND MODELLED EDDY KINETIC ENERGY DISTRIBUTIONS NEAR NORTHERN HEMISPHERE MID-LATITUDE JETS

William J. Schmitz, Jr. and
William R. Holland

Our earliest intercomparisons between North Atlantic data and eddy-resolving gyre-scale numerical model results focused on the amplitudes and largest horizontal scales in patterns of eddy kinetic energy, primarily abyssal. The two-layer quasi-geostrophic symmetric-double-gyre numerical experiments examined generally yielded relevant meridional and temporal scales but not particularly realistic zonal distributions. The intense mid-latitude jet and associated energetic segment of the model eddy field did not penetrate as far from the western boundary as observed, by a factor of two or three. The physical processes underlying zonal penetration have lately been studied in more detail and results compared with a better observational definition of the zonal distribution of abyssal eddy kinetic energy near the Gulf Stream.

Here, intercomparisons are extended to recent eight-layer model runs and new data which allow expansion of the investigation to the North Pacific near the Kuroshio Extension. Two such numerical experiments are shown to have realistic zonal, vertical and temporal scales (of eddy kinetic energy) in the vicinity of the Kuroshio Extension in one case and the Gulf Stream in the other. Thus, intercomparison is somewhat better for the North Pacific than in the North Atlantic. The model zonal mean speeds are significantly larger than observed, but vertical shears are in general agreement with the data. A longitudinal displacement between the locations of the maximum intensity in surface and abyssal eddy fields as observed for the North Atlantic is not found in the model results.

Model-equivalent isotherm height fluctuations are generally smaller than observed for the 15 degree isotherm in the North Atlantic.

Supported by: ONR Contract N00014-84-C-0134, NR 083-400 and NSF to the National Center for Atmospheric Research.

WHOI Contribution No. 6121.

THEORETICAL MODELS

ON THE ROLE OF TOPOGRAPHY IN THE OCEAN CIRCULATION

Paola Cessi and Joseph Pedlosky

The ideas developed by Rhines and Young (J. Mar. Res., 40 (suppl.), 559-596, 1982; J. Fluid Mech., 122, 347-367, 1982) are used to analyse the effect of topography in simple baroclinic layer models. The presence of longitude dependent topography induces strong internal jets with transports of the same magnitude as the interior flow. It is shown that the existence of these features is independent of the forcing structure at the top of the model ocean, of the topography form, and of the forcing in subsurface layers as long as the latter is small. Some examples are given both for forcings which, in the absence of topography, would give circulations closed in the interior and for forcings that require a western boundary current.

Topography also shifts the line of zero transport allowing for significant flow across the line of zero wind stress curl. Moreover, the lines dividing the subtropical gyre from the subpolar gyre are different in every layer, a feature absent in the flat bottom case.

Supported by: NSF Grants OCE82-14821 and ATM84-13515.

WHOI Contribution No. 6090.

MECHANISMS OF OCEANIC SUBDUCTION

Joyce M. Federiuk and James F. Price

We have extended Stommel's (Proc. Nat. Acad. Sci., 76, 3051-3055, 1979) kinematic model of oceanic subduction to include the dynamics of seasonal cycling as simulated by a one-dimensional model of the upper ocean. The model is driven by imposed heat

and momentum fluxes and calculates the seasonal evolution of the density and wind-driven velocity. Subduction occurs when the winter mixed-layer depth shoals through material surfaces from one year to the next. Because the late winter mixed-layer depth is set largely by a process of non-penetrative deepening due to heat (buoyancy) loss to the atmosphere, subduction is seen in this model to be one outcome of a net heat gain above the main thermocline during an annual cycle.

Even a modest surface heating of 15 W/m^2 (by either air/sea exchange or horizontal advection by the Ekman transport) will cause significant subduction. The volume of subduction depends upon both the heat gain and the density profile of the deep seasonal thermocline. Downward Ekman pumping also causes subduction by accumulating heat above the main thermocline. With pumping alone, our model gives subduction at the pumping rate. Either surface heating or downward pumping will cause the "Ekman demon" selection of late winter waters for subduction.

It is probable that both the surface heating and the pumping mechanisms contribute to subduction in subtropical gyres. Over much of the eastern subtropical North Atlantic the results will be a subduction rate that is considerably faster than would be expected from Ekman pumping alone.

Supported by: NSF Grant OCE82-14066
and ONR Contract N00014-76-C-0197,
NR 083-400.

WHOI Contribution No. 6054.

A DIAGNOSTIC INVESTIGATION OF KINETIC ENERGY BUDGETS IN A NUMERICAL MODEL

Melinda M. Hall

Data from a three-layer quasi-geostrophic eddy-resolving general circulation model have been used to investigate the downstream convergence of kinetic energy in the model's analog of the Gulf Stream as well as the kinetic energy budgets of the adjacent recirculation region. It is found that the downstream convergence of kinetic energy in the decelerating part of the jet is balanced primarily by ageostrophic flow against a pressure gradient, which may be interpreted as the sum of (1) a divergence of pressure work fluxes and (2) as conversion of kinetic to available potential energy in the region. In the western part of the recirculation, there is an opposite tendency for conversion of available potential energy to kinetic energy, as this flow feeds the accelerating Gulf Stream. The analysis also suggests

that instabilities are primarily barotropic in the decelerating jet region and baroclinic in the eastern recirculation regime. However, the two regions are coupled energetically, implying that a channel model enclosing the jet, thereby excluding energetic exchanges through its boundaries, may be inappropriate for investigating the instabilities of the jet.

In press: Journal of Geophysical
Research.

Supported by: NSF Graduate Fellowship;
NSF Grants OCE82-08746 and
OCE85-00598; and ONR Contract
N00014-82-C-0019, NR 083-004.

WHOI Contribution No. 5984.

A NUMERICAL STUDY OF BAROCLINIC INSTABILITY AT LARGE SUPERCriticalITY

J. Patrice Klein and Joseph Pedlosky

A series of numerical integrations of the two-layer quasi-geostrophic model were carried out to investigate the non-linear dynamics of baroclinically unstable waves at supercriticalities of $O(1)$. The results extend and are contrasted with the results of weakly non-linear theory valid only for small supercriticality.

Particular attention is paid to that sector of parameter space in which the transition from regular to aperiodic behavior is observed for weakly non-linear waves. It is found that aperiodic, chaotic behavior extends to parameter domains of higher dissipation as a consequence of finite amplitude effects as the supercriticality increases.

Sensitive dependence on parameters remains a hallmark of the system as intervals of chaotic, periodic, and steady solutions are observed. For the supercriticality of $O(1)$, a new stable periodic vacillation is observed.

As the supercriticality is increased, the system appears to "stiffen" non-linearly, e.g., wave amplitudes in the steady state are smaller than predicted by weakly non-linear scaling arguments. This stiffening can be explained in terms of the dynamics of a truncated system. However, the truncated system appears always to overestimate the domain of chaotic behavior since it misrepresents a subtle effect of the higher harmonics on the process of wave-mean flow interaction.

At much higher supercriticality (e.g. four times critical) where many waves are unstable, it is found that the linearly most unstable wave gives way to a longer, less unstable wave which comes to dominate

the solution in qualitative agreement with the predictions of weakly non-linear theory.

In press: Journal of the Atmospheric Sciences.

Supported in part by: NSF Grant ATM84-13515.

WHOI Contribution No. 6085.

EXPERIMENTS WITH CROSS-GYRE FLOW PATTERNS ON A BETA-PLANE

James R. Luyten and Henry M. Stommel

Patterns of flow are computed in a two moving layer, two gyre ocean circulation model to demonstrate how the location of a localized region of buoyancy flux determines the nature of meridional and cross-gyre buoyancy transport. The calculation is done by the method of characteristics. Problems of control of boundary conditions and location of shocks are discussed, using six examples.

Supported by: NSF Grant OCE84-14243 and ONR Contract N00014-84-C-0134, NR 083-400.

WHOI Contribution No. 6120.

GYRES DRIVEN BY COMBINED WIND AND BUOYANCY FLUX

James R. Luyten and Henry M. Stommel

The combined effects of buoyancy forcing and wind in a gyre scale steady ocean circulation are modeled using discrete layers with an interfacial flux, not necessarily vertical. The equations for vorticity conservation of the geostrophic flow in this system are fully non-linear, involving a Jacobian for the layer thicknesses. These equations are written in a form which can be solved by the method of characteristics. The form of these equations invites the interpretation that the geostrophic baroclinic flow is driven by buoyancy and steered by the wind. Two examples are solved and discussed, a subtropical gyre with heating and a subpolar gyre with cooling. In each case, there are distinct regimes of flow, depending upon whether the characteristics originate at the eastern or western boundaries of the model. A simple geometrical argument illustrates that the difference between these two regimes, the direct and indirect cells, depends upon the sign of the true vertical velocity relative to the interfacial flux.

Supported by: ONR Contract N00014-84-C-0134, NR 083-400 and NSF Grant OCE83-14722.

WHOI Contribution No. 6017.

THE BUOYANCY AND WIND-DRIVEN VENTILATED THERMOCLINE

Joseph Pedlosky

An analytical study of the combined wind-driven and buoyancy-driven thermocline problem is presented. The analysis is an extension of the ventilated thermocline model of Luyten, Pedlosky and Stommel (J. Phys. Oceanogr., 13, 292-309, 1983).

An exact solution for the ventilated region of the subtropical gyre is found under the condition that the ratio of the buoyancy flux to Ekman pumping is a function of latitude alone. It demonstrates the general westward shift of streamlines when the subtropical gyre is heated and the enlargement of the eastern shadow zone.

The flow in the shadow zone is described, in most instances, for the case of relatively small buoyancy flux. It is shown that the shadow zone, now in motion due to buoyancy forcing, splits into two zones. There is a broad eastward zone in which the deep flow is northeastward and a narrow zone between this branch and the ventilated fluid in which the shadow zone flow is returned in a relatively swift current, nearly preserving potential vorticity. For buoyancy/Ekman flux ratios which are nearly independent of position, the eastern branch of the shadow zone circulation lacks a beta spiral and the meridional transport can be simply calculated as a direct response to the heating.

For sufficiently large heating, the model predicts pinch-off of the cold water layer along a latitude circle in the ventilated zone, south of which the solution loses validity.

In press: Journal of Physical Oceanography.

Supported in part by: NSF Grant ATM79-21431.

WHOI Contribution No. 6070.

TURBULENCE AND MIXING,
FINE- AND MICRO-SCALE
PROCESSES

THE RELATIONSHIP BETWEEN VERTICAL,
DIAPYCNAL, AND ISOPYCNAL VELOCITY AND
MIXING IN THE OCEAN GENERAL CIRCULATION

Sara L. Bennett

On ocean general circulation scales, vertical velocity w is extremely small (10^{-5}), smaller than the horizontal velocity in scale. Nevertheless, it is of great importance to advective-diffusive and vorticity balances. In order to better understand the relationship between the cross-isopycnal (diapycnal) velocity, the mixing, and w in a non-ideal ocean in which some mixing and density sources are present, the velocity vector is decomposed into isopycnal and diapycnal components. Applying this decomposition to the exact continuity (mass conservation) equation, it is shown that while the diapycnal divergence is in principle the first correction to the isopycnal divergence for general circulation scales, the observational uncertainties in the isopycnal velocity are large enough that the diapycnal divergence cannot in practice be determined. Using these results, the horizontally-averaged near-vertical (diapycnal) velocity computed by Wunsch, Hu, and Grant (J. Phys. Oceanogr., 13, 725-753, 1983) in a model of the South Pacific (28-43°S) is reconsidered. It is shown that their calculation of diapycnal velocity from isopycnal mass convergence is not consistent with uncertainties in the isopycnal velocity and that the implied mixing cannot be accounted for with simple diffusion models and salt-fingering alone.

In press: Journal of Physical
Oceanography.

Supported by: ONR Contract N00014-85-
C-0001, NR 083-004.

WHOI Contribution No. 5901.

MASS TRANSFER TO AND FROM
SMALL PARTICLES IN THE SEA

Gabriel T. Csanady

Slowly sinking particles exchange mass with their liquid environment if dissolution processes within the particles maintain a surface concentration excess or deficiency χ_0 of a soluble substance above

background. If the exchange is controlled by diffusion in the liquid phase, the total mass loss is proportional to χ_0 , diffusivity D , and particle diameter d . If advection associated with the sinking of the particle dominates over diffusion, the exchange rate varies as $\chi_0 D^{2/3} d^2$, and is weakly affected by particle density and fluid viscosity. This is the case for spherical particles of a diameter greater than about 70 μm .

The resulting dissolution rate per unit depth of sinking is constant for large particles, but increases sharply once the particles are small and slow enough for mass exchange to be controlled by diffusion. With oxygen supply supposed the rate-controlling process of particle decomposition, a realistic depth of decomposition of order 1 km is calculated for 200 μm diameter spherical particles. The generation of an oxygen minimum at such depths then requires the production near the sea surface of sufficiently large organic particles in sufficient numbers.

In press: Limnology and Oceanography.

Supported by: DoE Contract DE-AC02-
79EV10005.

WHOI Contribution No. 6032.

UPPER OCEAN, SURFACE
LAYER PROCESSES
AND METEOROLOGY

WHITECAPS AND THE PASSIVE REMOTE SENSING
OF THE OCEAN SURFACE

Edward C. Monahan and
Iognaid G. O'Muircheartaigh

While the descriptions, in terms of the basic meteorological and oceanographic parameters, of the Beaufort velocity, U_b , and of whitecap coverage, W , provided in this paper are by no means complete, these formulations should be more useful to those designing satellite sensors capable of detecting sea surface foam than those now quoted in the remote sensing literature. It follows from the description of bubble spectra that the practice of using a foam patch, produced in fresh water and stabilized with detergent, to calibrate microwave sensors that are to be employed to detect salt water whitecaps is one that might well be revised.

In press: International Journal of
Remote Sensing.

Supported by: ONR Contract N00014-85-
M-0065, NR 211-229.

WHOI Contribution No. 6110.

THE FRONTAL AIR-SEA INTERACTION EXPERIMENT
(FASINEX):

A STUDY IN THE BEHAVIOR OF THE COUPLED
ATMOSPHERIC AND OCEANIC BOUNDARY LAYERS IN
THE VICINITY OF AN OCEANIC FRONT, PART I:
BACKGROUND AND SCIENTIFIC OBJECTIVES

Steven A. Stage and Robert A. Weller

The Frontal Air-Sea Interaction Experiment (FASINEX) is a study of the response of the upper ocean to atmospheric forcing in the vicinity of an oceanic front in the subtropical convergence zone southwest of Bermuda, the response of the lower atmosphere in that vicinity to the oceanic front, and of the associated two-way interaction between ocean and atmosphere. FASINEX is planned for the Winter and Spring of 1985-86 with an intensive period in February and March 1986 in the vicinity of 27°N, 70°W, where sea surface temperature fronts are climatologically common. Measurements will be made from buoys, ships, aircraft, and spacecraft. This article gives a brief history of FASINEX and presents its scientific goals. An article in next month's Bulletin will describe the experimental plan.

Published in: Bulletin of the American
Meteorological Society, 66, 12,
1511-1520, 1985.

Supported by: ONR Contract N00014-84-
C-0134, NR 083-400.

WHOI Contribution No. 6033.

THE FRONTAL AIR-SEA INTERACTION EXPERIMENT
(FASINEX):

A STUDY IN THE BEHAVIOR OF THE COUPLED
ATMOSPHERIC AND OCEANIC BOUNDARY LAYERS IN
THE VICINITY OF AN OCEANIC FRONT, PART II:
EXPERIMENTAL PLAN

Steven A. Stage and Robert A. Weller

The Frontal Air-Sea Interaction Experiment (FASINEX) is a study of the response of the upper ocean to atmospheric forcing in the vicinity of an oceanic front in the subtropical convergence zone southwest of Bermuda, the response of the lower atmosphere in that vicinity to the oceanic front, and of the associated two-way inter-

action between ocean and atmosphere. FASINEX is planned for the Winter and Spring of 1985-86 with an intensive period in February and March 1986 in the vicinity of 27°N, 70°W, where sea surface temperature fronts are climatologically common. Measurements will be made from buoys, ships, aircraft, and spacecraft. A previous article gave a brief history of FASINEX and presented its scientific goals. This article describes the FASINEX experimental plan.

In press: Bulletin of the American
Meteorological Society.

Supported by: ONR Contract N00014-84-
C-0134, NR 083-400.

WHOI Contribution No. 6034.

SATELLITE OBSERVATIONS OF
SEA SURFACE COOLING BY HURRICANES

Lothar Stramma, Peter C. Cornillon
and James F. Price

Sea surface cooling due to 13 hurricanes in the western North Atlantic between September 1981 and December 1984 is examined using satellite-derived sea surface temperature (SST) fields. Some SST cooling is observed in all cases; however, because of cloud cover and the fairly weak signal in some cases, we see pronounced cooling along an extensive and continuous portion of track for only three strong hurricanes. The persistence of cooling following the passage of a hurricane varies from a few days to at least 16 days. The amplitude of cooling is moderately well correlated with hurricane strength and is as large as 3.5°C. When the hurricanes move rapidly, the maximum cooling occurs well to the right of the track (approximately 70 km), while for slowly moving hurricanes the maximum cooling occurs near or on the track. Diurnal sea surface warming caused by low wind speed is found within 600 km of the hurricane center.

In press: Journal of Geophysical
Research.

Supported by: ONR Contracts N00014-81-
C-0062 and N00014-76-C-0197, NR
083-400.

WHOI Contribution No. 6063.

LARGE DIURNAL SEA SURFACE TEMPERATURE
VARIABILITY: SATELLITE AND
IN SITU MEASUREMENTS

Lothar Stramma, Peter C. Cornillon,
Robert A. Weller, James F. Price
and Melbourne G. Briscoe

Data from a surface mooring located in the Sargasso Sea at 34°N, 70°W between May 1982 and May 1984 were compared with satellite data to investigate large diurnal sea surface temperature changes. Mooring and satellite measurements are in excellent agreement for those days on which no clouds cover the site at the time of the satellite pass. During the summer half year a 20% chance exists at 34°N, 70°W for a diurnal warming of more than 0.5°C with values of up to 3.5°C observed in the two year period studied.

The diurnal warming observed at the mooring has been simulated well by a one-dimensional model driven by the local heat and momentum fluxes. Under conditions of very light wind and strong insolation that produce the largest surface warming, the surface mixed-layer depth reduces to the convection depth, and wind-mixing becomes unimportant. The thermal response is then very strongly surface trapped, making it likely that such events have been under-reported in routine ship observations.

In all cases observed, the spatial extent of warming events as determined by satellite data are well correlated with the atmospheric pressure patterns. Conditions giving rise to the largest diurnal warming events are often associated with a westward-extending ridge of the Bermuda high. Such meteorological patterns give rise to very large areas of significant heating. In the region studied, 57°W to 75°W and 29°N to 43°N, diurnal warming of more than 1°C is shown on occasion to cover areas in excess of 300,000 km², with warming of more than 2°C covering areas in excess of 130,000 km².

In press: Journal of Physical
Oceanography.

Supported by: ONR Contracts N00014-81-
C-0062 (URI) and N00014-76-C-0197,
NR 083-400 (WHOI).

WHOI Contribution No. 5953.

T E C H N I C A L R E P O R T S

PROGRAMS FOR COMPUTING PROPERTIES OF
COASTAL-TRAPPED WAVES AND WIND-DRIVEN
MOTIONS OVER THE CONTINENTAL
SHELF AND SLOPE

Kenneth H. Brink and David C. Chapman

Documentation for listings are presented for a sequence of computer programs to be used for problems in continental shelf dynamics. Three of the programs are to be used for computing properties of free and forced coastal-trapped waves. A final program may be used to compute wind-driven fluctuations over the continental shelf and slope.

Prepared for: NSF under Grant OCE84-
08563.

WHOI Technical Report 85-17.

MOORED CURRENT METER AND WIND RECORDER
MEASUREMENTS NEAR POINT CONCEPTION,
CALIFORNIA: THE 1983 OPUS OBSERVATIONS

Kenneth H. Brink, Dolores H. Chausse
and Russ E. Davis

The OPUS (Organization of Persistent Upwelling Structures) program deployed two vector-measuring current meter (VMCM) moorings near Point Conception, California, during April-July 1983. Current and temperature data from these moorings are summarized here. In addition, data from two nearby NDBC (National Data Buoy Center) meteorological buoys are presented.

Prepared for: NSF under Grants OCE82-
13968 and OCE80-14942.

WHOI Technical Report 85-1.

LOW-RATE DISCHARGE OF VARIOUS
ELECTROCHEMICAL BATTERIES FOR USE WITH
OCEANOGRAPHIC INSTRUMENTS

Alfred J. Ciesluk, Brian J. Guest,
Craig D. Marquette and George H. Tupper

The endurance of self-sustained oceanographic instruments is generally limited to battery energy. Tests were initiated to measure the capacities of several types of electrochemical batteries when discharged at temperatures and rates typical of oceanographic use. Battery systems represented are alkaline-manganese dioxide, mercuric-oxide, and lithium-sulphur oxychloride. Results of tests completed so far are presented. A brief overview of

those batteries best suited for use with self-sustained oceanographic instruments is included as an appendix.

Prepared for: ONR under Contract
N00014-76-C-0197, NR 083-400.

WHOI Technical Report 85-13.

HYDROGRAPHIC DATA FROM R/V OCEANUS CRUISE 133, LEG VII

George P. Knapp and Henry M. Stommel

Hydrographic data collected during R/V OCEANUS Cruise 133, Leg VII are presented. These data include temperature, salinity and dissolved oxygen observed at standard levels by a Neil Brown Instrument Systems' CTD-O₂ profiler and salinity, dissolved oxygen, silicate, phosphate, and nitrate values at the observed depths of the collected water samples. Ninety-four stations were occupied on a meridional section at (nominally) 52° West from Brazil to Greenland. Also presented is a series of sectional profiles of the six observed parameters as a function of depth.

Prepared for: NSF under Grant OCE80-15789.

WHOI Technical Report 85-38.

MOORED CURRENT METER DATA FROM THE ATLANTIC NORTH EQUATORIAL COUNTERCURRENT NEAR 6°N 28°W (MARCH-OCTOBER 1984) VOL. XXXVII

Ellen Levy and Philip L. Richardson

This third and final report presents current and wind data from a three part mooring deployment in the Atlantic North Equatorial Countercurrent near 6°N and 28°W. A Vector Averaging Wind Recorder (VAWR) measured wind velocity, sea surface temperature, air temperature, barometric pressure, and solar insolation. Four Vector Measuring Current Meters (VMCM) measured current velocity and temperature at depths of 20, 75, 150, and 300 m. The mooring was deployed on March 26, 1984 and recovered on October 12, 1984.

Prepared for: NSF under Grants OCE82-17112 and OCE82-11108.

WHOI Technical Report 85-7.

CODE-2: MOORED ARRAY AND LARGE-SCALE DATA REPORT

Richard Limeburner, editor

The Coastal Ocean Dynamics Experiment (CODE) was undertaken to identify and study the important dynamical processes which govern the wind-driven motion of coastal water over the continental shelf. The initial effort in this multi-year, multi-institutional research program was to obtain high-quality data sets of all the relevant physical variables needed to construct accurate kinematic and dynamic descriptions of the response of shelf water to strong wind forcing in the 2 to 10 day band. A series of two small-scale, densely-instrumented field experiments of approximately four months duration (called CODE-1 and CODE-2) were designed to explore and to determine the kinematics and momentum and heat balances of the local wind-driven flow over a region of the northern California shelf which is characterized by both relatively simple bottom topography and large wind stress events in both winter and summer. A more lightly instrumented, long-term, large-scale component was designed to help separate the local wind-driven response in the region of the small-scale experiments from motions generated either offshore by the California Current system or in some distant region along the coast, and also to help determine the seasonal cycles of the atmospheric forcing, water structure, and coastal currents over the northern California shelf.

The first small-scale experiment (CODE-1) was conducted between April and August 1981 as a pilot study in which primary emphasis was placed on characterizing the wind-driven "signal" and the "noise" from which this signal must be extracted. In particular, CODE-1 was designed to identify the key features of the circulation and its variability over the northern California shelf and to determine the important time and length scales of the wind-driven response. The second small-scale experiment (CODE-2) was conducted between April and August 1982 and was designed to sample more carefully the mesoscale horizontal variability observed in CODE-1. This report presents a basic description of the moored array data and some other Eulerian data collected during CODE-2. A brief description of the CODE-2 field program is presented first, followed by a description of the common data analysis procedures used to produce the various data sets presented here. Then basic descriptions of the following data sets are presented: (a) the coastal and moored meteorological measurements, (b) the moored current measurements, (c) array plots of the

surface wind stress and near-surface current measurements, (d) the moored temperature and conductivity observations, (e) the bottom pressure measurements, and (f) the wind and adjusted coastal sea level observations obtained as part of the CODE-2 large-scale components.

Prepared for: NSF under Grants OCE80-14941 and OCE84-17769.

WHOI Technical Report 85-35.

SURFACE DRIFTER MEASUREMENTS IN THE
ATLANTIC NORTH EQUATORIAL COUNTERCURRENT
1983-1985

Philip L. Richardson and
Christine M. Wooding

Thirty freely drifting drogued surface buoys were tracked by satellite in the vicinity of the Atlantic North Equatorial Countercurrent from February 1983 to February 1985 as part of the SEQUAL (Seasonal Equatorial Atlantic) Experiment. Buoys were launched at several different times of the year in order to sample the Countercurrent in different seasons. The purpose was to measure the seasonal variation of the Countercurrent in relation to wind forcing.

The basic data set consists of buoy trajectories and sea surface temperature, velocity, and wind speed along the trajectories. A comparison is made between the data from the buoys and from a current meter mooring near 6°N, 28°W. The main results presented here consist of the collection of figures which show trajectories and time series data along the Countercurrent and in the North and South Equatorial Currents, Guinea Current and North Brazil Current.

Prepared for: NSF under Grant OCE82-08744.

WHOI Technical Report 85-31.

HYDROGRAPHIC DATA FROM WARM CORE RING 82-B

Marvel C. Stalcup, Terrence M. Joyce,
R. Lorraine Barbour and Jane A. Dunworth

Hydrographic data from three cruises to Warm Core Ring 82-B during April-August 1982 are presented. These data include a sampling of the 2 db pressure, temperature, salinity, and oxygen measurements obtained with a Neil Brown CTD-0₂ together with water sample measurements of salinity, oxygen, silica, nitrate and phosphate. Charts showing the station positions and selected profiles of the various parameters are pre-

sented. Bi-monthly cruises aboard the R/V ENDEAVOR showed little change had occurred within the ring between April and June. Interactions between the ring and the Gulf Stream before the August cruise resulted in about a 90% reduction in volume.

Prepared for: NSF under Grant OCE80-16983.

WHOI Technical Report 85-29.

A COMPILATION OF MOORED CURRENT METER AND
WIND RECORDER DATA, VOLUME XXXVIII,
LONG-TERM UPPER OCEAN STUDY (LOTUS),
(MOORINGS 787, 788, 789, 790, 792)
APRIL 1983 - MAY 1984

Susan A. Tarbell, Ellyn T. Montgomery
and Melbourne G. Briscoe

The Long-Term Upper Ocean Study (LOTUS) was a two-year field experiment near 34°N, 70°W, designed to acquire a continuous set of measurements of currents and temperatures in the upper, open ocean together with local hydrography, meteorology, and mesoscale oceanographic features. The first scientific moorings were deployed in May 1982. The first year of mooring data, from May 1982 - April 1983, is presented by Tarbell, Pennington and Briscoe (WHOI Tech. Rept. 84-36, 1984). The second year of mooring data, from April 1983 - May 1984, when the final mooring recovery occurred, is presented here.

Prepared for: ONR under Contracts
N00014-76-C-0197, NR 083-400 and
N00014-84-C-0134, NR 083-400.

WHOI Technical Report 85-39.

MARINE POLICY
AND OCEAN MANAGEMENT PROGRAM
Paul M. Fye, Acting Director

INTERNATIONAL OCEAN TRANSPORTATION:
PRESENT AND FUTURE

Bernhard Abrahamsson

This paper outlines major technological changes in ships in the post-WWII period and where we may be heading in the near as well as distant future. It explores the relationships between trade, cargoes, and markets, on the one hand, and ships, ports, and cargo handling, on the other. Growing economies generate trade which relies on efficient shipping. To transport larger volumes of all kinds of cargoes, larger and faster ships have been created. To utilize the higher speeds properly, port time has been minimized by vastly improved cargo handling methods. Recent concerns for the marine environment and seafarers' safety have resulted in new international conventions which entail new "constraints" and rules pertaining to both commercial and technical operations. These conventions, formulated in the IMO and UNCTAD, together with economic developments and trade will be the main determinants of future shipping technology.

In press: Global Mobility, Center for Advanced Research in Transportation, College of Engineering and Applied Science, Arizona State University, 1985.

Supported by: Pew Memorial Trust; J.N. Pew, Jr. Charitable Trust; and Marine Policy and Ocean Management Center.

A SPECIAL MARINE RESERVE FOR THE
GALAPAGOS ISLANDS

James M. Broadus

The unique value of the natural systems of Ecuador's Galapagos Islands has been recognized at least since Darwin's historic visit in 1835. More recent scientific work has established that the marine habitats of the Galapagos archipelago are of comparable importance. Many of the islands' endemic organisms depend on the marine environment, which itself contains a high degree of endemism and large habitat diversity. The long-pending issue of a marine park or reserve for the Galapagos is one of the major questions facing coastal area and marine resources management there. While the national policy of Ecuador for the onshore area of the Galapagos Islands stresses conservation of the natural environment, no clear policy has been defined for the marine area. Because the Galapagos marine environment is virtu-

ally pristine, an obvious opportunity exists for the orderly establishment of special management provisions that preserve the habitats and traditional uses of this important marine area. The paper reviews the status of efforts to create such a park or reserve and describes an ongoing collaborative project between a private U.S. research institution and the Government of Ecuador to develop a realistic and workable approach as part of an integrated coastal and marine resources management scheme.

In press: Proceedings of Coastal Zone '85.

Supported by: Tinker Foundation, Inc.; Johnson Endowment; and Marine Policy and Ocean Management Center.

ASIAN PACIFIC MARINE MINERALS
AND INDUSTRY STRUCTURE

James M. Broadus

Eventual development of marine minerals potential in the Asian Pacific would likely draw on technology, skills, and experience of the emerging international seabed mining industry. As a result of strategic behavior by its firms, this small-numbers industrial "strategic group" has created a level of capacity for seabed mining exploration and R&D that far exceeds the near-term level of activity expected in seabed mining. The paper reports on the nature of preproduction industrial structure (or "protostructure") in seabed mining and draws implications for efforts to develop the resource potential of Asian Pacific marine minerals. Seabed minerals exploration and R&D services might be offered to Asian Pacific nations at bargain (below unit cost) prices by firms with first-starter advantages in the emerging industry. However, cautionary notes are included about constraints on the economic potential of the region's deep-sea minerals such as manganese nodules, polymetallic sulfides, and cobalt crusts.

In press: Journal of Marine Resource Economics.

Supported by: Pew Memorial Trust and Department of Commerce, NOAA, Sea Grant College Program Grant NA80AA-D-00077 (R/S-7).

WHOI Contribution No. 6084.

POOR FISH OF REDONDO:
MANAGING THE GALAPAGOS WATERS

James M. Broadus

In recent years, there has been a world-wide explosion of tourism concerned with wildlife, wildlife areas, and scenic beauty. For the nearly 8,000 residents of the physically inhospitable Galapagos Islands, virtually isolated 1,000 kilometers to the west of mainland Ecuador, this is a promising development. For the archipelago's unique natural systems, however, it could be ominous.

Significant progress in protecting the archipelago was made by the government of Ecuador in 1959, when it created the Galapagos National Park. The park includes about 90 percent of the islands' land area. Although national policy for the terrestrial area of the Galapagos Islands stresses protection of the natural environment, no comprehensive policy exists for the Galapagos marine area.

This pristine area is of great scientific interest and of vital importance to the archipelago's terrestrial organisms. If a comprehensive management program cannot be devised and successfully implemented for this watery treasure, we must surely be pessimistic about what can be achieved for other such marine areas elsewhere in the world.

Published in: *Oceanus*, 28, 1, 95-99,
Spring 1985.

Supported by: Tinker Foundation, Inc.;
Johnson Endowment; and Marine
Policy and Ocean Management Center.

FISHERMEN'S EVALUATIONS OF LIMITED ENTRY:
A LONGITUDINAL STUDY OF THE
CALIFORNIA ABALONE FISHERY, 1976-1979

Biliana Cicin-Sain and Maynard E. Silva

While limited entry represents a fishery management tool that is being adopted with increasing frequency by nations throughout the world, few empirical evaluative data on the effects of limited entry are available. This paper reports results from a 1979 longitudinal study of the California abalone fishery -- a fishery in which entry was limited in 1977, and which we have studied prior to and after the inception of limited entry.

This article analyzes the evaluations of the perceived costs and benefits of limited entry made by fishermen who have remained in the fishery, fishermen who have exited the fishery, processors, and resource managers. We discuss the per-

ceived effects of limited entry on a variety of variables: the resource, the fishermen, the price and availability of the product, other fisheries, the consuming public, and the local community. The findings suggest a mixed picture of the benefits and costs accruing from limited entry -- which contradicts, in part, hypotheses found in the theoretical literature on limited entry.

Supported by: Department of Commerce,
NOAA, National Sea Grant College
Program Grants 04-9-M01-189
(R/NP-1-7C) and 80AA-D-00077
(E/L-1); Pew Memorial Trust; and
Marine Policy and Ocean Management
Center.

WHOI Contribution No. 4992.

FISHERIES DEVELOPMENT IN THE THIRD WORLD:
THE ROLE OF INTERNATIONAL AGENCIES

Dean E. Cycon

International development assistance agencies play an important role in the transfer of scientific and technical information. Inevitably, such information is laden with values reflecting the culture and society of origin. Recipient developing nations do not necessarily share either the cultural values or the societal mechanisms which give rise to and make useful the information, tools and processes developed in the West. Thus a given technological or management innovation may produce wholly unintended results, profoundly impacting the resource base or the socio-economies of fishing communities in the developing world. The impact may be felt most severely by the small-scale or artisanal fishing communities that produce one-third of all food fish consumed worldwide and an even greater amount of the fish consumed in the developing world. The present orientation of international aid to fisheries must be re-examined to insure consideration of the local social and economic impacts as well as to encourage efficient utilization and preservation of fisheries.

Supported by: J.N. Pew, Jr. Charitable
Trust and Marine Policy and Ocean
Management Center.

LEGAL AND REGULATORY ISSUES
IN UNDERWATER ARCHAEOLOGY

Dean E. Cycon

Discoveries of underwater archaeological resources or lost treasures have been occurring rapidly due to the development of sophisticated sensing and recovery technology. Archaeologists and treasure hunters alike have begun to range around the world in search of the sunken keys to maritime history. Yet there are as many different approaches to regulating the search for and recovery of artifacts as there are different nations. This article looks at the major issues of jurisdiction and control of underwater archaeology or cultural heritage under national and international law. It also highlights the different regimes employed to regulate on-site work, and advises the archaeological and salvage communities to research and understand the legal and regulatory regimes prior to a large commitment of funds and energy to expeditions of this type.

Published in: *Oceanus*, 28, 1, 78-84,
Spring 1985.

Supported by: J.N. Pew, Jr. Charitable
Trust and Marine Policy and Ocean
Management Center.

MANAGING FISHERIES IN DEVELOPING NATIONS:
A PLEA FOR APPROPRIATE DEVELOPMENT

Dean E. Cycon

The extension of fisheries jurisdiction to two hundred miles under the exclusive economic zone principle has brought a major share of the world's fisheries resources under the control of the developing world. The developing nations have sought to upgrade their harvesting and marketing potential through increased development of this resource. Yet the form and substance of the management models, techniques and equipment being employed to "modernize" the fisheries may have a devastating effect upon the millions of small-scale fishermen who provide a large share of the world's catch. Modern systems that ignore social relations and indigenous conservation techniques may have a negative impact upon both the fisherman's welfare and the biological integrity of the stock. An "appropriate fisheries development" model, incorporating features of the indigenous systems and sensitive to the socio-economy of the fishing communities, should be explored.

In press: *Natural Resources Journal*.

Supported by: J.N. Pew, Jr. Charitable
Trust and Marine Policy and Ocean
Management Center.

PIRACY AT SEA: THE MODERN CHALLENGE

Dean E. Cycon

The collected and edited proceedings of a two-day international conference at WHOI that examined the resurgence of piracy at sea. Participants discussed the social and economic reasons for this resurgence, which is seen from Southeast Asia, to West Africa, to South America and the Caribbean. The international legal regime to control piracy was examined and suggestions made to remedy its inadequacy in light of the growth of piracy in extended territorial waters around the world.

In press: Westview Press, Boulder, CO.

Supported by: J.N. Pew, Jr. Charitable
Trust; Johnson Endowment; and
Marine Policy and Ocean Management
Center.

PLANNING AND MANAGING BRAZIL'S
COASTAL RESOURCES

Dean E. Cycon

With a 7,400 kilometer coastline, Brazil faces an enormous task in the planning and management of the various resources within the coastal zone. The article examines the range of resources and their potential, the conflicts among users, the geographic and geologic dimensions of the coastal zone, the range of agencies on the federal and state level that participate in the management, and the legal regime that is developing in Brazil to regulate and guide exploitation and use of these resources.

In press: *Coastal Zone Management Journal*.

Supported by: J.N. Pew, Jr. Charitable
Trust and Marine Policy and Ocean
Management Center.

WHEN WORLDS COLLIDE: THE EFFECT OF
DEVELOPMENT UPON INDIGENOUS PEOPLE

Dean E. Cycon

Around the world, the ancestral and present-day lands of indigenous peoples

are under attack from the developer's bulldozer, the oilman's rig and dynamite, and the miner's open pits. Water pollution, flooding, deforestation and disease have been the legacies of development for the native peoples of various countries. Yet these people are generally the most underrepresented group within their own countries and at world forums. The article examines the impact of development upon indigenous peoples in four countries and analyzes their legal remedies. A model is presented to mitigate the problem of internationally funded developmental impacts.

Supported by: J.N. Pew, Jr. Charitable Trust and Marine Policy and Ocean Management Center.

WHO OWNS THE TITANIC?

Dean E. Cycon

Ownership of lost or abandoned property at sea has always been a thorny issue. When property has been lost for decades and is found after a diligent search, the finder is generally entitled to a liberal award, which can often amount to title, by the internationally respected rules of maritime law. In the case of the TITANIC, the greatest civilian maritime disaster of all time, many potential claimants are stepping forward to seek title or salvage claims. Several governments are seeking international protection for the underwater site as a marine memorial. Former owners and insurers of the vessel and its cargo may seek recognition of their claims. Private salvors, lured by the huge profits to be made from the sale of artifacts and book and movie rights, are gearing up for what may be an impossible assault on the 12,000-foot-deep submerged site. International law provides a potential protective mechanism through the Law of the Sea Convention, but that agreement has not taken effect, nor has the United States ratified it.

Published in: *Oceanus*, 28, 4, 94-95, Winter 1985/86.

Supported by: J.N. Pew, Jr. Charitable Trust and Marine Policy and Ocean Management Center.

CAN STATES SURVIVE THE THRESHER SHARK CASE?

Timothy Eichenberg

This article explains how *Exxon v. Fischer*, a recent Los Angeles federal dis-

trict court decision, is likely to affect state-federal relationships established under the Coastal Zone Management Act of 1972 with regard to regulating the impacts of energy development upon coastal and marine resources. It describes the legislative history of the CZMA and the experience of states under the statute's "federal consistency" provisions. It then explains how the controversy between *Exxon's* exploration for oil in the Santa Barbara Channel and California's commercial fishing industry affects the broader legal issues and standards of the CZMA appeal provisions. The rationale of *Exxon v. Fischer* is compared with the Supreme Court decision in *Secretary of Interior v. California* and the article discussed how the legal and political reaction to the *Exxon* case is likely to affect future marine policy issues.

In press: *Territorial Sea*.

Supported by: J.N. Pew, Jr. Charitable Trust and Marine Policy and Ocean Management Center.

OFFSHORE OIL: ANOTHER CHAPTER

Timothy Eichenberg

This article discusses how a recent federal district court decision in Los Angeles, entitled *Exxon v. Fischer*, marks a new chapter in the continuing controversy surrounding the ability of states to influence offshore oil and gas development. The article traces the traditional political alliances and legal regimes that govern the federal OCS oil and gas program and how these are affected by the federal consistency authority conferred to states under the Coastal Zone Management Act of 1972. It explains how these policies are affected by *Exxon v. Fischer* which holds that states may not attempt to reconcile conflicts between oil exploration and commercial fishing operations on the OCS. Finally, the article attempts to predict the likely repercussions on other marine policy issues.

In press: *Oceanus*.

Supported by: J.N. Pew, Jr. Charitable Trust and Marine Policy and Ocean Management Center.

ECOLOGY OF THE LOGGERHEAD SEA TURTLE, Caretta caretta

Nat B. Frazer

This paper is a summary of the ecology of the loggerhead sea turtle, *Caretta caretta*, based primarily on data gathered in a 20-year tagging study of nesting females on Little Cumberland Island, Georgia, USA. Loggerheads crawl onto the beach from May to August and lay an average of about 3 nests during the nesting season, at intervals of about 13 days apart. The average number of nests can change from year to year. In some years, the turtles average 4 or more nests; in other years, the average drops below 3. The most nests ever recorded for a loggerhead in one year was 7. Loggerheads lay up to 185 eggs in a nest, but the average nest contains about 120 eggs, and this average doesn't change much from year to year. Only about 4% of the turtles return to nest one year later. About 50% return in two years; 32% in three years; 11% in four years; 3% in five years.

Loggerhead eggs are eaten by raccoons, pigs, crabs, and humans. The only major natural predator of large juveniles and adult loggerheads (other than man) is the shark. Every year, however, shrimp boats drown thousands of large loggerheads in their nets. Although some people believe that sea turtles live to be very old, our research indicates that today they do not live longer than 60 years. The conservation efforts at Little Cumberland Island are also discussed.

In press: El Condor: Revista de la Universidad del Turabo.

Supported by: Pew Memorial Trust and Marine Policy and Ocean Management Center.

PROBLEMS IN THE STUDY OF MARINE TURTLES

Nat B. Frazer

Sea turtle scientists are faced with a number of problems as they attempt to understand the ecology of these turtles. In this paper, I discuss some of the problems that occur and also present attempts to solve them.

One of the most troubling problems is that there is no way to determine the age of a sea turtle. We are just beginning to develop ways of estimating a sea turtle's age, but the methods are far from perfect. I discuss some of them and show what has been done so far.

Another problem is that the tags put on adult turtles to study their survival sometimes either fall off or are cut off by fishermen. Therefore, I have developed ways to adjust estimates of adult survival for tag loss stochastically. I discuss the estimation of adult survivorship before

and after adjusting for tag loss.

A third problem is to determine what proportion of the eggs will survive to become adult turtles. No one has yet been able to tag or mark enough hatchlings over a long enough period to measure this survival. I discuss some of the ways sea turtle scientists have suggested solutions to this problem for the future. Then I show how the traditional mathematics of population ecology can be used to estimate survival to adulthood with data presently available.

In press: El Condor: Revista de la Universidad del Turabo.

Supported by: Pew Memorial Trust and Marine Policy and Ocean Management Center.

SURVIVAL FROM EGG TO ADULTHOOD IN A DECLINING POPULATION OF LOGGERHEAD TURTLES *Caretta caretta*

Nat B. Frazer

Previous estimates of survival rates of sea turtle eggs or hatchlings to adulthood depend upon the assumption that their populations are neither increasing nor decreasing in numbers. The assumption is made in spite of the fact that recent interest in sea turtle demography stems from the belief that populations are in decline. This paper presents estimates of the survival rate from egg to maturity necessary to maintain a population of loggerhead turtles, *Caretta caretta*, at its present observed rate of decline. Conventional demographic equations were used along with values of adult survivorship, fecundity and alternative estimates of age at maturity from the literature. Results indicate that the proportion of eggs surviving to adulthood lies between 0.0009 and 0.0018 in this declining population, as opposed to an estimated value of 0.0025 under the erroneous assumption that the population is stationary. These results suggest that previous studies have overestimated survival of eggs or hatchlings to maturity in sea turtle populations. The methodology may be used to assess gross survivorship from egg to adulthood in increasing or decreasing populations of any species in which adults and eggs are more easily studied than are juveniles.

In Press: Herpetologica, 42, 1, 1986.

Supported in part by: Pew Memorial Trust and Marine Policy and Ocean Management Center.

WIDECAST: HELP FOR CARIBBEAN SEA TURTLES

Nat B. Frazer

Whether one defines conservation as preservation or as management for sustained utilization, the six species of sea turtles in the Caribbean and the Gulf of Mexico are in need of stringent conservation measures. Sea turtles and their eggs have been exploited by all the inhabitants of the Caribbean. As direct exploitation of turtles declined in the present century, the pace of industrial and agricultural development increased dramatically, destroying sea turtle foraging and nesting areas.

The problem now emerging in sea turtle management -- recovering an over-exploited resource in the face of habitat destruction -- is likely to be applicable to other living marine resources as the global human population continues to expand. Sea turtles can serve as a case study for the development of methods to ensure international cooperation in preventing the further decline of depleted living resources, restoring them to former levels of abundance, and maintaining them for sustained use.

WIDECAST stands for the Wider Caribbean Sea Turtle Recovery Team and Conservation Network. The Team is an international, non-governmental, volunteer group of 11 sea turtle scientists and conservationists, supported by a network of over 100 individuals and organizations. The WIDECAST effort will ensure that each country is presented with an action plan that is formulated as part of a Caribbean-wide, coordinated effort at sea turtle conservation.

Published in: *Oceanus* 28, 1, 100-102, 1985.

Supported by: Pew Memorial Trust and Marine Policy and Ocean Management Center.

A GROWTH CURVE FOR GREEN TURTLES,
Chelonia mydas, IN THE DANISH WEST INDIES
1913-1914

Nat B. Frazer and Rosamund C. Ladner

Few growth curves are available for green sea turtles, *Chelonia mydas*, in the wild. An early study of the movements of juvenile green turtles in waters surrounding the Danish West Indies (Schmidt, 1916) provides data that we used to construct the first growth curve for green turtles in the area (now the U.S. Virgin Islands). Measurements of carapace lengths of juvenile green turtles captured and recaptured

between 1913 and 1914 were fit to a von Bertalanffy growth equation using modern analytical methods not available when Schmidt's (1916) study was conducted. The von Bertalanffy equation for green turtle growth in Caribbean waters of the early 20th century is:

$$L_t = 121.64(1 - 0.96e^{-0.075t})$$

indicating an age at maturity of between 27 and 33 years. The growth curve and the estimate of age at maturity could provide information valuable to conservationists as well as a rare opportunity to assess long-term changes in important attributes of the natural history of sea turtles.

In press: *Copeia*.

Supported by: Pew Memorial Trust and Marine Policy and Ocean Management Center.

WHOI Contribution No. 5829.

ANNUAL VARIATION IN CLUTCH SIZE
AND FREQUENCY FOR LOGGERHEAD TURTLES,
Caretta caretta, NESTING AT
LITTLE CUMBERLAND ISLAND, GEORGIA, USA

Nat B. Frazer and James I. Richardson

Clutch size and frequency were assessed for loggerhead turtles, *Caretta caretta*, nesting at Little Cumberland Island, Georgia, in order to examine annual variation in reproductive characteristics. Mean annual clutch size varied significantly over a 19 yr period from 1965-1983, although significant differences were found only between mean clutch sizes in the highest and the lowest years.

Analysis of observed clutches indicated that mean annual clutch frequency varied significantly over a 10 yr period from 1974-1983. Significant differences were found between mean observed clutch frequencies in the highest year and the two lowest years as well as between the second highest year and the lowest year. Adjusting observed clutch frequencies for potential unobserved clutches resulted in significant differences between the year with the highest estimated mean annual clutch frequency and the three lowest estimated mean annual clutch frequencies.

Published in: *Herpetologica*,
41, 3, 246-251, 1985.

Supported in part by: Pew Memorial Trust and Marine Policy and Ocean Management Center.

THE GALAPAGOS ISLANDS (ECUADOR):
THE USE OF SCIENTIFIC AND TECHNICAL
INFORMATION IN COASTAL PLANNING

Arthur G. Gaines and Efrain Perez

The purpose of this study is to assess the extent to which shortcomings in coastal public works projects and in conservation of the coastal environment and disparities between stated preservation objectives and observed realities in the Galapagos Islands are the result of inadequate scientific and technical information. Long-standing concern for preservation of the remarkable flora and fauna of the Galapagos was first effectively institutionalized with the formation of the Charles Darwin Foundation (CDF), which for more than 25 years has promoted research, conservation and public education on the unique natural systems of these islands. CDF has also promoted and assisted with development of an Ecuadorian legal and management structure to protect the Galapagos Islands. In recent years, their research laboratory, the Charles Darwin Station, has added staff positions in the biological disciplines and in "human ecology."

Over the years, the Ecuadorian Government has repeatedly reaffirmed its support of conservation, but it is also compelled to address sovereignty and public welfare in the archipelago. The public service infrastructure that came to the Galapagos with provincial designation in 1973 included some technical information sources, but has been dominated by a development orientation. Interaction among ministries in the Islands is often not effective, leading to a single-purpose approach that can create new problems as it resolves old ones. In addition, the ministries are geographically distant, and typically removed by several bureaucratic tiers, from head offices on the mainland where decisions are made.

The creation of the Galapagos National Institute (INGALA) in 1979 brought planning, development, and conservation functions of the Government under a single lead agency; it provided a structure to organize the use of technical information and the operations of other ministries and agencies on these remote islands. In the past five years, master-planning by special presidential committees has been employed to identify problems and strategems and to rank long-term objectives for the Islands and institutions operating there.

Despite important areas of success, progress in conservation in the archipelago has been frustrated by developments surrounding a rapidly increasing resident population. Superimposed on this since 1980 has been cataclysmic variability in

the Islands already harsh climate from an El Nino event as well as sharp variability in municipal and provincial level budgets, stemming from fluctuations in international oil revenues and currency devolution. Much of the short-term failure of public works projects and frustration in realization of conservation objectives could result from these factors, which made routine operation of Government bodies on the Islands untenable. Compared to other parts of the world, the availability of scientific and technical information in the Galapagos Islands appears quite good; however, as elsewhere in the world, their use in public works and policy formulation is often ad hoc and not effectively institutionalized. Lack of distinction between aesthetic, social, or value judgements on one hand and ecological considerations on the other contributes further to confusion in applying available scientific and technical resources to coastal planning on the Islands.

In press: Proceedings of Coastal Zone '85.

Supported by: Tinker Foundation, Inc.; Johnson Endowment; and Marine Policy and Ocean Management Center.

INFLUENCE OF FISHERMEN'S PREFERENCES ON
THE SUCCESS OF COMMERCIAL FISHERY
MANAGEMENT REGIMES

Michael C. Healey

Fishermen may opt for goals of stock rebuilding and stable yield when fish stocks are depleted and the short-term outlook for catches is poor but reject these goals when a good year class appears. The purpose of this study was to determine whether this apparent ambivalence among fishermen is a consequence of changing preference for short- and long-term returns or can be accounted for by the change in short-term pay-off associated with good recruitment. I derived realistic short- and long-term pay-offs by exploiting a population model of the Gulf of Maine herring (*Clupea harengus*) stock under two regimes. The goal of one regime was to obtain long-term stable yields while the goal of the other was to take windfall yields from occasional good year classes. I used a multi-attribute utility model to determine if there was a set of preference weights for short- and long-term returns that would cause fishermen logically to choose the stable yield regime when the short-term outlook was poor but to choose the windfall yield regime when the short term outlook was good. Such a set of

preference weights did exist. If attributes other than short- and long-term returns were included in the analysis, then ambivalence was logically possible regardless of the weight assigned to these other attributes--provided the other attributes scored higher in the windfall yield regime but not if they scored higher in the stable yield regime. These results suggested that more acceptance management regimes could be designed based on a knowledge of fishermen's preferences.

Published in: North American Journal of Fisheries Management, 5, 173-180, 1985.

Supported in part by: Pew Memorial Trust and NOAA, Office of Sea Grant.

PATENT ACTIVITY IN THE SEABED MINING INDUSTRY

Porter Hoagland III

Patent issues are one way to observe the behavior of private firms and government agencies at a formative stage in an industry's development when, for strategic reasons, these participants are careful about disclosing details of their activities. The seabed mining industry is a good example of an industry in its formative stages. This industry has been characterized in large part by the research and development (R&D) of technology to recover minerals from deep ocean polymetallic nodules and to process them metallurgically into metal products. The nearly 400 seabed mining patents that have been granted worldwide are a rough measure of this R&D activity. Patent issues can reveal several interesting aspects of an industry: (a) the identity of participants; (b) the generic type of technology; (c) the technological concentration of patent holders; (d) the technological integration of patent holders; and (e) the timing of inventive activity. In some cases, industrial motivations and strategies may be inferred from these aspects. Moreover, seabed mining might be subject to the cyclical fluctuations of markets for the metals contained in polymetallic nodules. Patent activity could provide some insight into the nature of a possible seabed mining industry cycle.

Supported by: NOAA, National Sea Grant College Program Grants NA80AA-D-00077 (R/S-7), NA83AA-D-00049 (R/G-7) and NA84AA-D-00033 (R/G-7) and Johnson Endowment.

WHOI Technical Report 85-20.

THE ROLE OF THE U.S. COAST GUARD

Porter Hoagland III

Throughout its history, the missions of the United States Coast Guard have paralleled ocean-use patterns in the United States. Today, the Coast Guard has regulatory or enforcement authority for drug smuggling, illegal immigration, a coastal military "maritime defense zone," piracy, search and rescue of lives in peril at sea, buoys and lighthouses, vessel traffic, port security, fisheries management, ocean dumping, oil pollution, and marine sanctuaries, among others. These multiple and sometimes disparate responsibilities are tied together by the Coast Guard's ability to operate in the marine environment. Because the Coast Guard's responsibilities enhance the welfare and safety of U.S. citizens in their use of ocean resources, the Coast Guard contributes in a very real sense to the security of the nation.

Published in: Oceanus, 28, 2, 67-73, 1985.

Supported by: J.N. Pew, Jr. Charitable Trust and Marine Policy and Ocean Management Center.

SEABED MINING PATENT ACTIVITY: SOME FIRST STEPS TOWARD AN UNDERSTANDING OF STRATEGIC BEHAVIOR

Porter Hoagland III

Intellectual properties, such as patents, are an important source of information in the field of resource management and technology. Patent issues are one way to observe the behavior of private firms and government agencies at a formative stage in an industry's development when, for strategic reasons, these participants are careful about disclosing details of their activities. The seabed mining industry is a good example of an industry in its formative stages. This industry has been characterized in large part by the research and development (R&D) of technology to recover minerals from deep ocean polymetallic nodules and to process them metallurgically into metal products. Seabed mining might be subject to the cyclical fluctuations of markets for the metals contained in polymetallic nodules. Patent activity could provide some insight into the nature of a possible seabed mining industry cycle. This article is a condensation of research reported in Woods Hole Oceanographic Institution Technical Report 85-20.

In press: Journal of Resource
Management and Technology.

Supported by: Pew Memorial Trust;
Marine Policy and Ocean Management
Center; and NOAA, National Sea
Grant College Program Grants
NA80AA-D-00077 (R/S-7), NA83AA-D-
00049 (R/G-7), and NA84AA-D-00033
(R/G-7).

SECURITY ASPECTS OF DANISH AND NORWEGIAN LAW OF THE SEA POLICIES

Finn Laursen

Two Scandinavian countries, Denmark and Norway, border waters where the East and West meet. Of the four Soviet fleets, two are based close to Scandinavia, viz. the Northern Fleet at Murmansk and the Baltic Fleet at Kaliningrad. The Baltic Fleet must pass the Danish straits to reach the North Sea and the Atlantic. Only the Northern Fleet is straits-free and ice-free all year, but it is handicapped by having to pass the Svalbard passage between the Svalbard archipelago and Northern Norway, (Finnmark) and the Greenland-Iceland-United Kingdom (GIUK) gap to reach the strategic North Atlantic. The GIUK gap is very much NATO home-territory, partly because of Norwegian and Danish NATO membership. In this connection it should be remembered that Greenland and the Faroe Islands are parts of the Kingdom of Denmark. The water concerned, from the Baltic through the Belts, the Kattegat, the Skagerrak, the North Sea, the Norwegian Sea, the Greenland Sea to the Barents Sea, have all witnessed increased Soviet naval activities in recent years. This gives important security aspects to the marine policies of Denmark and Norway. This article endeavors to outline some of these security aspects and how they have affected or may affect the law of the sea policies of the two countries. Straits passage and delimitation conflicts are covered in depth. Delimitation problems in general and expansion of maritime zones are relevant to the extent that there is a danger of "creeping jurisdiction" in new maritime zones of limited functional scope, such as fishing or economic zones. Offshore oil obviously has some security implications, too. Must platforms be protected in case of crisis or war? How much control and surveillance must follow the introduction of 200-mile fishing or economic zones? Both Scandinavian countries studied here will increasingly have to consider these types of questions. Security taken in a broad sense, including military security as well as security of important energy

and other resource supplies, is clearly at stake. This seems to have been more fully realized in Norway than in Denmark.

Supported by: Pew Memorial Trust;
Marine Policy and Ocean Management
Center; and Danish Security and
Disarmament Committee.

WHOI Contribution Number 6042.

ECONOMIC AND OPERATIONAL CONSIDERATIONS OF OFFSHORE DISPOSAL OF SEWAGE SLUDGE

Thomas M. Leschine and James M. Broadus

A simplified economic analysis relates the comparative internal costs of nearshore and distant sewage dumpsite options in the New York Bight to the reduction in external costs required to move to a more distant site. Indicative approximations of the relative internal costs associated with the alternative sites are generated using three different approaches. First, an assumption that deepwater dumping is just a projection of current nearshore practice and capability to the distant sites leads to a ratio of Deepwater Dumpsite-106 to 12-mile site of about 4.6 for New York City's short-run variable transportation costs. Second, annual cost estimates reported by all dumpers in the region show ratios ranging from 2.7 to 5.5, with a weighted average ratio of 4.0. These estimates also suggest that there may be a minimum efficient scale for ocean sludge dumping in the $(0.5-1.0) \times 10^6 \text{ m}^3 \text{ y}^{-1}$ range, and that there may be unexploited economies of scale in current practice. Third, using a sludge disposal transportation cost algorithm developed for the U.S. Environmental Protection Agency, we find ratios for long-run total transportation costs ranging from 3.6 to 4.7 for those examples closest to current practice. Long-run cost estimates are quite sensitive to vessel size and sludge thickness. We do not measure dynamic costs behavior but argue that there is reason to expect long-run total costs to be lower than simple projections of current short-run costs. A reasonable, rough method for planning purposes might be that the ratio of total internal cost for dumping at the deepwater site to that for the nearshore site is about 4, although the use of sludge dewatering or other technologies not now in use in the region could alter this estimate.

Published in: "Deep-Sea Waste Disposal, 1985." Wastes in the Ocean, Vol. 5.

Supported by: Office of Marine
Pollution Assessment; NOAA Grant
81RA-D-00013; and Pew Memorial
Trust.

WHOI Contribution No. 5320.

THE RECRUITMENT AND APPLICATION OF
SCIENTIFIC INFORMATION IN COASTAL AND
MARINE RESOURCES MANAGEMENT:
ANALOGS TO THE GALAPAGOS ISLANDS

Scott McCreary

This report discusses the recruitment and use of scientific information for coastal resources management in archipelagos, the Cape Verde Islands and the Republic of the Seychelles, that share certain features with the Galapagos Islands of Ecuador. Three international coastal resources management programs--the UNESCO Man and the Biosphere Program (MAB), the Eastern Caribbean Natural Areas Management Program (ECNAMP), and the UNEP Regional Seas Programs--are also examined for relevance to the Galapagos case. For each archipelago, the report presents a brief national profile, summarizes major resource issues, describes the roles scientists have played in coastal management, assesses the outcomes of scientific involvement, and outlines possible barriers to the use of information.

The scientific community has had a limited presence in Cape Verde, except in the fisheries sector. The Seychelles have many features in common with the Galapagos. Integration of scientific information there has been strongest in species protection, special area designation, and preparation of resource inventories. The three international programs vary in their geographic scope, formality, and precision. ECNAMP has made impressive contributions to site planning, but is not likely to be a promising model for archipelago-wide management. The Southeast Pacific Regional Seas Program may present a useful framework in which to cooperate with Ecuador's neighbors. MAB has sponsored designations of dozens of biosphere reserves worldwide and specific projects emphasizing tourism/endemic species interaction. MAB may provide a useful network for information exchange.

Supported by: Tinker Foundation, Inc.
and Johnson Endowment.

WHOI Technical Report 85-14.

FEEDSTOCK SELECTION FOR
SMALL- AND INTERMEDIATE-SCALE FUEL
ETHANOL DISTILLERIES

Mark Meo

A variety of commercial and experimental starch- and sugar-rich crops were evaluated for their suitability as feedstocks for both small-scale, on-farm and intermediate-scale, off-farm fuel ethanol production in California's Sacramento Valley. Solutions of linear programming models indicated that sweet sorghum is the least-cost feedstock for on-farm production of 50,000 gallons of fuel ethanol per year. Fodder beet proved to be the least-cost feedstock for off-farm production of one million gallons of fuel ethanol per year.

Published in: Journal of Soil and
Water Conservation, 40, 4, 364-366,
1985.

Supported by: Pew Memorial Trust and
Marine Policy and Ocean Management
Center.

EXPANSION OF THIRD WORLD NAVIES

Michael A. Morris

The proliferation of independent Third World states in the postwar period brought in its wake a belated awareness of the promise of offshore resources and the need for maritime defense and led, in due course, to a fairly general, if uneven, naval expansion. In the course of this expansion, a number of potent Third World navies eventually came into being. Regional powers with powerful navies emerged and a Third World naval hierarchy began to be discernible.

The purpose of this study is to develop and apply a methodology--the Third World naval hierarchy--for analyzing the implications of the spread of maritime weapon systems in the Third World. Major implications include the assessment of conflict prospects and the possibilities for arms control. Part I of this study sets forth the Third World naval hierarchy. Part II applies the hierarchy to the various regions. Overall conclusions are derived in part III.

In press: Macmillan, London.

Supported by: J.N. Pew, Jr. Charitable
Trust and Marine Policy and Ocean
Management Center.

SOUTHERN CONE MARITIME SECURITY
IN THE POST 1984 TREATY CONTEXT

Michael A. Morris

Only Argentina and Chile share the southern tip of South America, where their interests are more immediate and extensive than those of other states. Here the Southern Cone narrows and ends in an archipelago pointing toward the Antarctic peninsula. In the case of both Argentina and Chile, the interoceanic passages, archipelagos, and ocean areas at the tip of South America occupy a central position in national military strategy. At the same time, their relationship to Argentine and Chilean military strategy is distinctive.

Military interests constitute but part of the mosaic of Argentine and Chilean interests at the tip of the continent. Economic and legal interests are important components of Argentine and Chilean approaches to the area, but since the tip of the Southern Cone has been conflict-prone the political and military interests of the two most concerned powers, Argentina and Chile, have tended to predominate there.

The 1984 Argentine-Chilean Treaty of Peace and Cooperation was a significant achievement in conflict resolution and could lead as well to greater economic, political and even military cooperation between the two states. Nonetheless, the general area at the tip of the Southern Cone (including the southwestern portion of the South Atlantic, the Falkland Islands, the Antarctic peninsula and environs, the Drake Passage, and the southeastern portion of the Pacific Ocean) remains conflict-prone. Clarification of the nature of ongoing conflicts of interest in the aftermath of the 1984 treaty, it is hoped, will enhance understanding of remaining obstacles to cooperation and thereby encourage realistic channels for conflict resolution.

In press: Ocean Development and
International Law: The Journal of
Marine Affairs, 1986.

Supported by: J.N. Pew, Jr. Charitable
Trust and Marine Policy and Ocean
Management Center.

THE 1984 ARGENTINE-CHILEAN
PACT OF PEACE AND FRIENDSHIP

Michael A. Morris

In 1984, Argentina and Chile concluded a Treaty of Peace and Friendship that has important economic, political, and strate-

gic implications for the southernmost part of the Americas. Argentine President Alfonsín claimed that the treaty is a broad step toward "peace, integration, and disarmament in Latin America." There are, nonetheless, difficult obstacles that must be overcome if the ambitious aims of the treaty are to be realized.

Published in: Oceanus, 28, 2, 93-96,
1985.

Supported by: J.N. Pew, Jr. Charitable
Trust and Marine Policy and Ocean
Management Center.

CBMs IN COMPARATIVE PERSPECTIVE:
LATIN AMERICA

Michael A. Morris and Victor Millan

In contrast to the situation on the European continent, the perception of the variable "confidence" differs considerably in other latitudes. Nor are the causes of distrust the same for all regions. In order to apply confidence building measures (CBMs) effectively in Latin America, much wider concerns than enhancing confidence in strictly military matters must be considered, even though this is the focus of CBMs in Europe.

In spite of differences in perspective regarding CBMs in the military field, these have been included in proposals to resolve the Central American crisis. Related CBMs have been included in the Declarations of Ayacucho and Washington, as well as in diverse subregional agreements, including the Andean Pact and SELA (Latin American Economic System). There is an urgent need in Latin America to promote such CBMs in the military area and to extend them to political, economic, and social problems as well.

The general context for CBMs is set forth in an introductory section followed by examples of CBMs tailored to the two Latin American subregions (the Caribbean Basin and South America) and to some prominent conflicts, and a final section presents some conclusions about confidence building measures in Latin America.

In press: Confidence Building Measures
and International Security, 1985.

Supported by: J.N. Pew, Jr. Charitable
Trust and Marine Policy and Ocean
Management Center.

AN HISTORICAL PERSPECTIVE ON THE
INCIDENCE OF PIRACY

M. J. Peterson

Piracy has existed as long as legitimate maritime trade, yet its severity differs from time to time and place to place. Pirates require three things for success: sources of loot, markets for disposal of loot, and secure bases for rest, resupply, and ship repair. The amount of piracy occurring at any time in any place depends on the extent to which all three are available to pirates.

Precautions by ship owners, shippers, and ships' crews provide a first line of defense by making loot more difficult to secure. Yet whenever piracy reaches a high level, naval patrols and more effective law enforcement in and near ports are required to suppress pirates.

Though individuals provide the demand for pirate loot, government policy has often been responsible for conditions that increase this demand. Severe restrictions on trade, such as those adopted by the Ming emperors of China in the 15th century or the British government in the 17th century, do not stop trade. Rather, individuals quickly resort to smuggling and piracy to satisfy demand. Large-scale disruptions of trade patterns, such as those that accompanied the European arrival in the Indian Ocean and Southeast Asia, often push local mariners into piratical activity. Slave markets also encouraged piracy since few individuals voluntarily sell themselves into slavery. Rather, the markets were fed by prisoners of war and other captives. Finally, until the practice was abolished in the mid-nineteenth century, privateering encouraged piracy. First, it created legal markets for stolen goods because once the forms were followed, a privateer could sell the goods captured quite openly. Second, many of the crews who engaged in privateering during wartime were loath to return to the less lucrative carriage of legitimate trade and went into piracy instead.

Once pirates establish secure bases on an island or a remote stretch of coast, rooting them out is a task for navies or government coastal patrols. Historically, pirates established bases in places outside effective government control, such as remote islands. Today, such bases flourish only when governments are distracted by civil disorder, too weak to provide effective rule over all the territory they claim, or inclined to tolerate pirate activity because it fits in with some broader policy.

In press: Piracy at Sea: The Modern
Challenge. Westview Press,

Boulder, Colorado, 1986.

Supported by: Pew Memorial Trust;
Johnson Endowment; and Marine
Policy and Ocean Management Center.

ANTARCTIC IMPLICATIONS OF THE NEW
LAW OF THE SEA

M. J. Peterson

The ways in which changes in one international regime can affect others are demonstrated by influence of ideas adopted at the Third UN Conference on the Law of the Sea on current discussions of Antarctica's future. By 1975, changed fish and oil markets had increased interest in the potential of Antarctic resources to the point that participants in the Antarctic Treaty system could no longer follow their old policy of ignoring resource issues. However, agreements reached at UNCLOS III made it more difficult to resolve resource issues by supplementary agreements within the Antarctic Treaty framework.

Difficulties arose from two sources. First, agreement on the expansion of coastal state jurisdiction increased the potential value of Antarctic territorial claims. This led to greater claimant state efforts to win economic concessions for their continued acceptance of Antarctic Treaty provisions setting aside sovereignty questions to permit joint use of the continent. This has intensified the one disagreement among the parties capable of destroying the regime from within. Second, notions of common heritage adopted for the deep seabed encouraged attack on the Antarctic Treaty system from outside. A number of Third World governments have endorsed proposals to replace the Antarctic Treaty system with a UN-based management body.

Yet as long as the Antarctic Treaty participants remain united they will determine Antarctica's future. Even a united Third World coalition lacks the power to dislodge a united coalition of the Antarctic Treaty states. However, the Third World is not united on the issue because a number of Third World states participate in and prefer to retain the Antarctic Treaty system. Though negotiating an agreement on fuel and mineral resources will be more difficult, adoption of the Convention on the Conservation of Antarctic Marine Living Resources in 1980 indicates the sort of joint management the Consultative Parties expect to exercise.

In press: Ocean Development and
International Law.

Supported by: Pew Memorial Trust and
Marine Policy and Ocean Management
Center.

WHOI Contribution Number 5653.

ANTARCTIC POLITICS TODAY

M. J. Peterson

This introduction to a special issue on Antarctic affairs summarizes the current state of the rival efforts to amend and replace the Antarctic Treaty system. The 16 Consultative Parties are working to cover the gap left by the Antarctic Treaty's silence on resource issues by writing separate but related treaties on resource exploitation. The 1980 Convention on the Conservation of Antarctic Marine Living Resources and the continuing negotiations on an analogous fuel and mineral resource agreement are described and evaluated.

At the same time, a number of Third World governments not involved in the Antarctic Treaty system have proposed replacing it with a UN body. However, this effort is unlikely to succeed. Even a united Third World would be unable to dislodge the Consultative Parties since the latter include both superpowers and several second-rank powers. Yet the Third World is not united on the issue. Four Third World states are Consultative Parties and several others have acceded to the Antarctic Treaty. Only if the Consultative Parties had such serious disagreements that some of them decided to join the call for a UN body could the campaign to replace the Antarctic Treaty succeed. This is unlikely to occur in the foreseeable future. Hence, Antarctic affairs will continue to be managed by the Consultative Parties.

Published in: Current World Leaders,
28, 7, 1985.

Supported by: Pew Memorial Trust and
Marine Policy and Ocean Management
Center.

GOVERNING THE FROZEN SOUTH: THE ORIGIN AND EVOLUTION OF THE ANTARCTIC TREATY SYSTEM

M. J. Peterson

The Antarctic Treaty system provides an excellent case study for refining theories explaining how and why governments create, maintain, or discard international regimes to regulate their interactions on

particular issues or in certain geographic areas not subject to the sovereignty of particular states.

International regimes pass through several phases of existence: 1) creation, in which agreements are reached on the principles, norms, rules, and procedures of the regime, 2) establishment, in which the agreements are put into effect, 3) maintenance, and 4) modification, which can take the form of minor amendment, replacement by a new regime, or termination of the existing regime. The timing and success of each phase can be explained by looking at a combination of issue salience, the interests of participating governments, and the desires of the most powerful coalition forming among participants.

There were two attempts to create an Antarctic regime. The first, among the United States and the seven states asserting Antarctic territorial claims in 1948-49, failed. The second, among the seven claimants, the superpowers, and three other nonclaimants with a record of Antarctic activity in 1958-59, succeeded. The difference is explained largely by differences in the salience of Antarctic issues. In 1949, those issues were important enough to get on governments' foreign policy agendas, but not important enough to produce sustained attention or clear decisions. Matters drifted until they were overtaken by preparations for the International Geophysical Year (IGY) of 1957-58. The second attempt succeeded because the IGY gave Antarctic affairs enough salience to merit sustained attention and because the participating states, this time the seven claimants, the superpowers, and three other nonclaimants, were able to agree on a regime. Despite differences on other questions, both superpowers agreed that Antarctica should not be divided but left open for joint use. The other ten states involved were ready to accept this as at least a second-best regime.

The Antarctic regime was established within two years, a success helped by the fact that Antarctic affairs remained the province of small groups of decision-makers and scientists committed to the regime's success. Between 1963 and 1975, the regime was maintained with little difficulty. Nothing happened in the Antarctic or the wider international system to raise the salience of Antarctic issues or cause participating governments to reevaluate their interests.

The salience of Antarctic issues rose again in the early 1970s because changes in world fish and oil markets encouraged a reassessment of Antarctic resources. With the acceptance of 200 mile fishing zones, the Southern Ocean became one of the few places where distant water fishing fleets

could go without securing permission to fish from another government first. The 1973 oil crisis and price increase led to some interest in the possibility of exploiting Antarctic offshore hydrocarbons.

This rise in salience set off two efforts to modify the regime. The Antarctic Treaty Consultative Parties sought to amend the regime by adding agreements regulating resource exploitation. This effort led to the 1980 Convention on the Conservation of Antarctic Marine Living Resources and to a series of sessions aimed at producing an analogous agreement covering fuel and mineral resources on Antarctica or the Antarctic continental shelf. At the same time, a number of Third World governments campaigned for replacement of the Antarctic Treaty by a UN body to manage Antarctic affairs. So far, however, this effort at replacement has been stalled by the fact that proponents of replacement cannot forge a coalition strong enough to displace a united group of Consultative Parties. Only if there were a major falling-out among the Consultative Parties would there be a chance for replacement. A number of Third World governments now admit that and have begun reducing their demands.

Supported by: Pew Memorial Trust and Marine Policy and Ocean Management Center.

THE GENERAL ASSEMBLY IN WORLD POLITICS

M. J. Peterson

During its forty years of existence, the UN General Assembly has passed through three major eras: control by a stable US-led coalition of Western and Latin American states from 1947 through 1955, fluid alignments among various groups of states between 1956 and 1964, and control by a stable Third World coalition of developing African, Asian, and Latin American states since 1965.

The Assembly has performed similar functions in all three eras. Its influence has always been strongest in the agenda formation phase of world politics. The numerous weak states of the world, whether or not organized into a cohesive coalition of their own, have been able to use the Assembly's open agenda to force strong states to pay attention to their concerns. The General Assembly's influence in other phases of world politics has always been very weak. It has never monopolized international decision-making, being instead one among many sources of decisions. Though the Assembly can order other UN bodies to do certain things, implementation of its decisions has always rested mainly

on action of member states free to ignore the decisions.

The General Assembly has always been both an arena for conflict and a forum for arranging cooperation. Yet the apparent balance between conflict and cooperation has shifted with changes in the goals and resources of the controlling majority. The US-led majority had mildly reformist goals and ample power resources while the Third World majority has had revisionist goals but few power resources. This combination of ambitious goals and modest resources has forced the Third World coalition to take Western-created precedents for one-sided use of the Assembly, further allowing the arena to obscure the forum on many occasions. At the same time, however, the need for outside assistance in securing many of its goals has forced the Third World coalition to go further in the development of consensus methods for establishing cooperative programs, making the forum more suitable for organizing cooperation.

In press: George Allen & Unwin, Boston and London, 1986.

Supported in part by: Pew Memorial Trust and Marine Policy and Ocean Management Center.

OCEAN SCIENCE: ITS PLACE IN THE NEW ORDER OF THE OCEAN

David A. Ross

The oceans, which comprise over 70 percent of our planet, are still a relatively unknown environment. Nevertheless, they offer exciting potential for mineral and biological resources, a potentially safe disposal site for some human and industrial wastes, new sources of energy, control or modification of climate, a medium for transport of much of the world's trade, a military playground, and other potential not yet even considered. The study of the ocean necessary to achieve this potential is visualized by some countries as a form of power, by others as an opportunity, and by still others as a frustration because of their lack of marine science expertise. In any case, marine scientific research will be critical to those countries that wish to develop their new 200 nautical mile Exclusive Economic Zone (EEZ) and other marine areas having potential. Those countries without marine science expertise will be at a disadvantage unless they develop such capabilities and/or develop cooperative efforts in scientific research and training with those countries that have such skills. The

achievement of a country's marine objectives may often be more a function of national policy and politics than the ability to pose and solve the appropriate scientific or technical question.

Many scientists feel that marine research is approaching a very important crossroad. On one path are recent exciting scientific discoveries such as the deep-sea vents along oceanic spreading centers and their associated polymetallic sulfide deposits and exotic lifeforms or similarly our increasing understanding of air-sea interactions, and thus ultimately better climate prediction and even modification. These discoveries hold considerable promise for major advances in our use and exploitation of the ocean, that can also eventually impact on many other human endeavors. On the other path, however, are some aspects of the Law of the Sea (LOS) treaty that could severely reduce or restrict marine scientific research in large and important areas of the ocean. The challenge is to find an intermediate or new path that allows the continuation of important marine research, without scientists or countries becoming frustrated or diverted by the LOS treaty and other entanglements. Indeed, it may even be possible that the LOS treaty could yield positive benefits, but to achieve them and capitalize fully on present and new scientific discoveries will require innovative approaches towards marine research. It is to everyone's advantage that the ocean is used properly.

This paper comments on various aspects of the LOS treaty for marine scientific research, their implications for scientists and developing countries, and then concludes with some suggestions for improving marine science opportunities for all.

In press: The New Order of the Oceans: From Abundance and Freedom of the Seas to Scarcity and Management of the Uses of the Seas.

Supported by: Pew Memorial Trust; Marine Policy and Ocean Management Center; and NOAA, National Sea Grant College Program Grant NA83-AA-D-00049 (E/L-1).

WHOI Contribution No. 5706.

INTERNATIONAL MARINE SCIENCE
RESEARCH PROJECTS: INVENTORY AND ANALYSIS
OF SELECTED PROJECTS AT SEA GRANT
INSTITUTIONS--1985

David A. Ross and Judith Fenwick

The U.S. marine scientific community

continues to show an interest in marine research within foreign Exclusive Economic Zones and with foreign scientists and institutions, in spite of the problems, regulations, and increased formalization involved in cooperative international projects. This inventory of international marine science research projects at Sea Grant institutions resulted from discussions on the possible establishment of a U.S. office or center for international marine science cooperation. Such an office has been proposed as one mechanism to assist in developing international marine research projects.

The report analyzes data from 98 inventory questionnaires completed by Sea Grant institutions. It should serve as a reference piece for persons seeking information and assistance in initiating cooperative international marine science research projects. Projects are profiled by sources of funding, disciplines of principal investigators, geographic locations of projects, and general categories of research. Also included are summaries of the completed questionnaires, indexes for quicker access to pertinent areas of the summaries, and information for the reader with further questions or interest in contacting the principal investigator of a specific project.

Supported by: NOAA, National Sea Grant College Program Grant NA84AA-D-00033 (R/B-66); Pew Memorial Trust; and Marine Policy and Ocean Management Center.

WHOI Technical Report 85-22.

MARINE AND COASTAL PROTECTED AREAS
IN LATIN AMERICA

Maynard E. Silva and Ingrid DeSilvestre

In this article, the authors provide a definition of marine and coastal protected areas. Using this definition, they survey such areas in Latin America, considering the reasons for their establishment, arrangements for management, and problems associated with marine reserves in Latin America. The article concludes with an evaluation of the efforts to date to protect marine and coastal areas and resources. It also includes an extended table identifying, by country, the existing and proposed marine protected areas of the region.

In press: Coastal Zone Management Journal, 1986.

Supported by: Tinker Foundation, Inc.;

Johnson Endowment; and Marine
Policy and Ocean Management Center.

OCEAN RESOURCES
AND INTERGOVERNMENTAL RELATIONS:
THE RECORD TO 1980

Maynard E. Silva and Lauriston King

This book chapter examines the U.S. system of intergovernmental relations (IGR) for the management of ocean resources. Looking at several activities, the authors sketch out the various patterns of roles, authorities and responsibilities that existed for federal, state, and local governments. Specifically examined are fisheries, coastal zone management, ocean-based waste disposal, protection of endangered species and marine mammals, and OCS hydrocarbon development.

Five conclusions are drawn. First, the period of 1940-1980 saw a marked reformulation of IGR for these ocean resources and uses. Second, each resource or use seems to exhibit its own pattern of IGR. Third, the modifications in each subsystem of IGR occurred at different times and at different paces. Fourth, some of the modifications were intended; some were "accidental." And fifth, there was no uniform pattern of shifting authorities, roles, or responsibilities. That is, in some cases state governments became more prominent with respect to the management of a resource or activity. In other cases, the opposite was true.

In press: Ocean Resources and Intergovernmental Relations in the 1980s.

Supported by: J.N. Pew, Jr. Charitable Trust; Marine Policy and Ocean Management Center; and Texas A&M Sea Grant College Program.

THE LOUISIANA RESPONSE TO LAND SUBSIDENCE
AND COASTAL EROSION

Maynard Silva and Mark Meo

Based on interviews with representatives of state, local, and federal agencies and with private interests, this paper reviews and assesses the responses made in Louisiana to the related problems of land subsidence and coastal erosion. The paper begins with a short review of the scientific evidence which indicates that Louisiana is losing more than 40 square miles per year to these phenomena. The paper then examines the process by which the various agencies involved have created

policies and programs for addressing the problems of subsidence and erosion. The authors then enumerate the various strategies which have been adopted. The paper concludes with a few observations on the adequacy of the state, federal, local and private responses.

Published in: Proceedings of Oceans '85: Ocean Engineering and the Environment, 2, 594-599, 1985.

Supported by: NOAA, National Sea Grant College Program Grant NA84AA-D-00033 (R/S-13); J.N. Pew, Jr. Charitable Trust; and Marine Policy and Ocean Management Center.

THE POLITICAL ECONOMY OF THE
CITY/STATE INTERFACE

M. Estellie Smith

The growing concern with the extent and intensity of state management is argued to be grounded in the emergence of the managerial or bureaucratic revolution that marks the structures first observed in the ancient city-states. It is argued that, since cities are concentrated arenas for production and exchange, the exercises of control over income streams into consumption and investment (the latter being viewed as 'capital') created systems of state management directed to that end. State structures and processes have been grounded in the exercise of that control ever since. Implied in the paper is the argument that, as increased consumption requires increased capital investment (e.g., stock predation in the world's fisheries), the state must, by necessity, play an increasing role in managing the income streams of relevant or related groups. An understanding of the long-term dynamics of fisheries management is gained by the study of such macro-historical considerations and patterned trends.

Supported by: J.N. Pew, Jr. Charitable Trust and Marine Policy and Ocean Management Center.

THE RIGHT TO CHOICE:
POWER AND DECISION-MAKING

M. Estellie Smith

This is the final chapter in a collection of 12 papers (plus introduction) centered on "women in the fisheries." Joining the traditionally muted role of women in fishing communities with the more public and explicit role they are increasingly

playing (economically and politically, shoreside and at sea), the paper addresses the question of why women have, in the past, been perceived as powerless and not privy to decision-making in the productive area. This is related to their actual role as helpmate, co-producer, and active decision-maker. The analysis is thus used to move to the more general area of how decisions are made and the factors that are cognitively weighted by those deciding and those affected by the decisions as to the degree of participatory democracy (and lack of it) that exists in any group of producers. A model of two types of organizational structures is presented to identify supposedly "egalitarian" and "hierarchical" decision-making contexts and the effects such identifications have on the willingness to abide by such decisions.

In press: Memorial University, St. John's, Newfoundland.

Supported by: J.N. Pew, Jr. Charitable Trust and Marine Policy and Ocean Management Center.

GRADUATE STUDENTS

Abstracts of papers or theses submitted in 1985 by graduate students of the Woods Hole Oceanographic Institution Doctoral Degree Program and the Woods Hole Oceanographic Institution/Massachusetts Institute of Technology Joint Program in Oceanography/Oceanographic Engineering. Other papers authored or coauthored by graduate students are included in the departmental sections. Students are indicated by an asterisk in the Author Index.

MODERN SEDIMENTATION IN THE NORTHERN
BARENTS SEA: INPUT, DISPERSAL,
AND DEPOSITION OF SUSPENDED SEDIMENTS
FROM GLACIAL MELTWATER

Stephanie L. Pfirman

The modern depositional environment of the northern epicontinental Barents Sea varies from proximal to distal glacio-marine. The regional surface sediment distribution is controlled by erosion of shallow banks of the Pleistocene glaciated surface, with the fine material deposited in the deep basins. Near-bottom nepheloid layers are often observed, indicating that fine grained sediments are being transported under present conditions. Minor additional sediment is supplied by iceberg rafting englacial material and sea-ice containing aeolian, resuspended, and beach sediments.

Glacial flour is supplied by several large stable meltwater outflow locations along the ice front. Because the water is fresh and nearly the same temperature as the ambient coastal water, it is buoyant. Although the traction load deposits as the meltwater plume rises to the sea surface, sand (as well as finer material) may be suspended. This material deposits from suspension at some distance from the discharge location (dependent on both the sediment settling velocity and the velocity of the ambient coastal water, resulting in well-sorted deposits near the outflow location). Most of the sediment in suspension is observed to deposit within a 5 km radius of the outflow location, and suspended matter samples obtained 18 km offshore were at background levels. However, meltwater plumes can often be observed in the surface water (in satellite photographs) at distances of 30 km downstream, indicating transport of glacial sediments along the ice front.

Near the Nordaustlandet glacier front surface sediments are disturbed by glacial advances and retreats which mechanically rework the sediment surface. The southwestern portion of the glacier front, Brasvellbreen, surged 18 km between 1936 and 1938. An end moraine was deposited at the maximum extent of the surge. The ice then stagnated and disintegrated though calving. At present, the eastern portion of the Brasvellbreen ice front is active with frequent small (less than 50 m) glacier advances and retreats. Evidence for this is shown by the minor ridge and swale moraines in this eastern area.

Supported by: ONR Contract N00014-01-C-009; Norwegian Marshall Fund; and Norwegian Polar Research Institute.

BENZ(a)ANTHRACENE IN BENTHIC MARINE
ENVIRONMENTS: BIOAVAILABILITY,
METABOLISM, AND PHYSIOLOGICAL EFFECTS
ON THE POLYCHAETE Nereis virens

Anne E. McElroy

The fate of [^{14}C -12] benz(a)anthracene (BA) was followed in benthic microcosm experiments in the presence and absence of the polychaete Nereis virens. In concert with chemical analysis of BA and its metabolites in all components of the system, physiological and biochemical effects of exposure on Nereis were investigated. BA was introduced in three ways: already sorbed to the entire sediment reservoir; directly into the water column; or incorporated into a gelatin-based diet. Experiments ran from 4 to 25 days. Activity of BA and BA metabolic products was followed in sediments, worm tissue, and in the water column. $^{14}\text{CO}_2$ activity in the water column was also measured. Growth, oxygen consumption, ammonia excretion, adenylate nucleotide pools, and mixed function oxygenase activity of the worms were also monitored.

The presence of worms and the mode of introduction had significant effects on the fate of BA in this system. In experiments with sediments uniformly labeled with BA, worms increased flux of BA from the sediment, and after nine days, their presence led to increased rates of microbial mineralization of BA to CO_2 . In experiments where BA was added directly to the water column, worms mixed BA into the sediment, but had no net effect on removal of BA in the sediment to the water column. BA added to the water column and deposited at the sediment-water interface was more available for uptake by worms, microbial mineralization to CO_2 , and removal to the water column than BA sorbed to bulk sediments. Regardless of mode of introduction, worms were able to accumulate BA. However, bioavailability of BA previously sorbed to sediments was less than BA added to the water column and allowed to settle at the sediment-water interface. Of the three modes of introduction studied, BA ingested in a gelatin-based diet was most available for accumulation by Nereis.

Length of exposure and mode of introduction had significant effects on accumulation and metabolism of BA by Nereis. As total activity accumulated, the proportion remaining as parent compound decreased with time and was inversely correlated with relative efficiency for accumulation. The relative amounts of different metabolic products were also affected by time and mode of exposure. In all experiments, most activity recovered from worms

was present as metabolic products with only 2 to 23 percent remaining as parent compound. A significant portion (from 33 to 51 percent) of total activity was not extractable, indicating incorporation into macromolecular components.

Physiological and biochemical effects of BA exposure on *Nereis* were minimal. Subtle alterations in adenylate nucleotide pools were observed after 6 days in experiments with either sediment-sorbed BA or BA added directly to the water column. After 25 days of exposure to sediment-sorbed BA, worms showed increased rates of oxygen consumption and ammonia excretion. No significant changes in growth or activity of the mixed function oxygenase system were observed.

These experiments demonstrated: (1) that the presence of a large burrowing polychaete can have significant effects on the fate of PAH in the benthos; (2) that source can have significant effects on both fate and metabolism of PAH in the benthos; (3) that *Nereis virens* is capable of accumulating and metabolizing BA from the sediment, water column, or ingested food; and (4) that incorporation into cellular macromolecules is a major fate of accumulated BA.

Supported by: DoE/BLM Contract DE-AC02-77EV04256 A007, AA550-IA7-20; NOAA Contract 83-ABD-00012; Ocean Industries Program; Andrew W. Mellon Foundation; NWF/API Environmental Conservation Fellowship Program; Sigma Xi; and Woods Hole Oceanographic Institution.

THE REACTIVE TRANSPORT OF SUSPENDED PARTICLES: MECHANISMS AND MODELING

Richard S. Mercier

The computational modeling of the reactive transport of suspended particles is particularly challenging because particles settle differentially and they are involved in physiochemical reactions that are often nonlinear and sometimes fast with respect to the fluid turbulence. Examples of such reactions are particle coagulation, precipitation/dissolution, adsorption, and secondary nucleation. The kinetics of coagulation are examined and it is concluded that in the aquatic environment particle number concentration correlations are significant and that particles of size greater than about 0.1 micron tend to collide most often with particles that are much smaller in size, contrary to the theory of Hunt (1982). An improved model for the collision frequency function

for turbulent shear is proposed that takes into account the intermittency in the microscale shear rate. Extending the work of Daly (1984), a kinetic model of frazil ice growth is formulated and verified against experimental data. To incorporate fast, nonlinear reaction kinetics into a general transport model, the transport equation for the one-point, joint scalar probability density function (pdf) is employed. Pope's (1981) Monte Carlo technique for solving the pdf transport equation is extended to allow simulation over nonuniform grids. In addition, stochastic algorithms for simulating differential sedimentation and radial diffusion are developed. Finally, the capabilities of the model are demonstrated by simulations of frazil ice formation in a river, transport and deposition of sludge particles discharged from a coastal outfall, and desorption of trace elements from resuspended, contaminated sediments.

Supported by: Woods Hole Oceanographic Institution; NOAA; and EPA.

CELL CYCLE CONTROLS IN MARINE PHYTOPLANKTON

Daniel Vaulot

In general, phytoplankton growth is controlled by the essential environmental factors light and inorganic nutrients. Although these controls act at the level of the individual cell, most research on phytoplankton has focused on the population or community as the organizational level of interest. The broad goal of the present work was to understand how cell and population behaviors are coupled, using as examples two "model" marine phytoplankton species, *Thalassiosira weissflogii*, a diatom, and *Hymenomonas carterae*, a coccolithophorid. When grown in light/dark cycles, these two species display fundamentally different population division patterns. The diatom divides primarily during the light phase, whereas division is restricted to the dark period in the coccolithophorid.

Two approaches were used to examine the differences between these two species. First, the interaction between individual cells and light was modelled using the transition point hypothesis of Spudich and Sager (1980). This hypothesis states that a cell requires only a limited amount of light exposure before being committed to divide, and that cells deprived of light remain blocked in a discrete segment of the cell cycle. The model reconstructs the division behavior of a population from that of single cells, including

a provision for cell-to-cell variability. The model is able to reproduce the general features of division patterns of phytoplankton populations observed in periodic and transient light/dark regimes. Moreover, the model helped us to identify the underlying cell cycle phenomena responsible for the different division patterns displayed by the diatom and the coccolithophorid, and form hypotheses for the experimental phase of the research.

Second, the characteristics of cell populations were examined experimentally using flow cytometry to monitor the distribution of cellular constituents, in particular DNA, in experimental cultures subjected to changes in environmental conditions. We examined how cell cycle progression is controlled by light. It was found that the premises of the model were essentially correct, i.e. that cells were blocked in specific parts of the cell cycle when placed in the dark. The detailed aspects of light control in these two species, however, were somewhat more complex than the mechanisms proposed in the Spudich and Sager (1980) model. In the diatom, cells deprived of light could be arrested either in the G_1 and G_2 phases of the DNA cycle, but never in S. Cells arrested in G_1 proceeded through their cycle at a normal rate when reexposed to light, whereas those arrested in G_2 did not. In the coccolithophorid, the arrest point was in G_1 , and cell cycling characteristics appeared to change in the dark such that cycling was slower upon release than before arrest.

The control of limiting nutrients over the cell cycle was also examined experimentally and was found to be very similar in both species. Nutrient deprivation induced cell arrest in the early stages of the cell cycle, and a significant lag was observed upon release from limitation. Cell arrest position was dependent upon what nutrient was limiting in the diatom. Silicon starved cells arrested, on the average, later in their cycle than did cells starved of both nitrogen and silicon.

Finally, during the course of this investigation it was discovered that certain light/dark regimes induced gametogenesis in *T. weissflogii*. This was studied in detail using flow cytometric analysis of DNA, protein and chlorophyll fluorescence, and of forward angle scatter. A large fraction of a population which has been dark arrested for two days was observed to differentiate into male gametes upon re-exposure to light. Male gametes were also observed in continuous light. In contrast, female gamete production was observed only in photoperiodically entrained populations. Flow cytometric analysis

proved to be a valuable tool for monitoring the differentiation process and holds promise for future studies of life cycle phenomena in phytoplankton.

The single cell approach developed in this work provides a new perspective for the study of phytoplankton ecology. A sound understanding of the regulation of cell cycle progression in these organisms is important for the accurate measurement of in situ growth rates and for modeling population growth dynamics in the upper mixed layer of the oceans.

Supported by: NSF Grants OCE-8121270, OCE-8118475-A01, OCE-8316616 and CEE-8211525; ONR Grant N00014-83-K-0661; Whitaker Fund; and Woods Hole Oceanographic Institution.

HORIZONTAL AND VERTICAL STRUCTURE OF VELOCITY, POTENTIAL VORTICITY, AND ENERGY IN THE GULF STREAM

Melinda M. Hall

From October 1982 to October 1983 a current meter mooring reaching from the bottom into the thermocline was deployed for the first time in the Gulf Stream at 68°W. The temperatures, pressures, and velocities at the uppermost instrument indicate the Gulf Stream moved back and forth across the mooring site, such that the entire Stream was sampled in time; hence, the data may be used to examine horizontal as well as vertical structure of the Stream. The two key points to the success of the analysis are: 1) the well-defined relationship between temperature and cross-stream distance in the thermocline, enabling the use of the former as a horizontal coordinate; and 2) a daily-changing definition of Gulf Stream flow direction based on the shear between the thermocline and 2000 m depth. Time-series of daily-rotated velocities may be used to calculate empirical orthogonal functions for the long and cross-stream vertical structures, which are decoupled and are respectively baroclinic and barotropic. Using the inferred horizontal coordinate one can estimate mass, momentum, and kinetic energy fluxes for four individual events when the entire Stream swept by the mooring. The results agree well with historical data. Bryden's (1980) method has been used to calculate vertical velocities from the temperature equation; the resulting time-series of w are visually coherent throughout the water column and their vertical amplitude structure is reminiscent of that for a two-layer system. The rms vertical velocities are large ($0(0.05 \text{ cm/s})$), and

these as well as other estimates have been used to explore the validity of the quasi-geostrophic approximation at the mooring site. The Rossby number for the thermocline flow is about 0.3, and for the deep flow is ≤ 0.1 .

The entire data set may also be used to construct a horizontal and vertical profile of velocity in the Gulf Stream, from which a cross-section of the mean potential vorticity can be produced. The latter shares many common features with cross-sections from past work for a nearby site, as well as analogous data from a three-layer numerical model, thus suggesting that they are robust features of Gulf Stream-like currents. These features are, in particular, a strong jump from low to high values crossing the Stream from south to north and a change in the sign of the potential vorticity gradient on isothermal surfaces for $T > 12^\circ\text{C}$.

To complement the analysis of the observational data, a set of diagnostic calculations has been performed on an eddy-resolving general circulation model to provide a complete picture of the kinetic energy budgets of the free jet and its environs. It is found that the downstream convergence of kinetic energy in the decelerating jet is balanced primarily by an ageostrophic flow against the pressure gradient, which in turn implies some conversion of kinetic to available potential energy in the region. Energetic analysis of the observations as well as the numerical data suggest barotropic and baroclinic instabilities may be equally important to the kinetic energy budgets in the Stream.

Because there is but one mooring, the dynamics governing the fluctuations remain elusive. Nonetheless, a kinematic framework is proposed which is consistent with the data and accounts for a variety of unusual features that arise in the original analysis (for example, distinct asymmetries in the four Gulf Stream crossings and the rather large vertical velocities). It is suggested that the data we are now capable of collecting is proffering fundamentally new attributes of the Gulf Stream, which must be included and accounted for in future theoretical work.

Supported by: NSF Grant OCE-8208746
and ONR Contract N00014-82-C-0019,
NR 083-004.

TRANSPORT OF TRACE METALS IN NEARSHORE SEDIMENTS

William R. Martin

The focus of this thesis is on rates of transport of metals both across the sediment/water interface and within the sediment column of nearshore sediments. The early diagenesis of several first-row transition metals exhibiting a variety of behaviors in the ocean -- Mn, Fe, Co, Ni, and Cu -- has been studied intensively at a site in Buzzards Bay, Mass. By limiting the study to a single site, independent measurements over the seasonal cycle of the concentrations of the metals in pore water, of the pore water constituents important to metal cycling, and of particle and solute transport rates could be made at the same site. In addition, a direct, in situ study of the interaction of chemical and transport processes was undertaken using radiotracer techniques. Thus, the study emphasizes the mechanisms of metal cycling near the interface of nearshore sediments.

Transport rates were estimated using excess ^{234}Th distributions for particle transport and pore water ^{222}Rn deficit distributions for solute transport. Particle transport rates, modeled by analogy to Fickian diffusion, ranged from $7\text{--}80 \times 10^{-8} \text{ cm}^2/\text{sec}$, with excess ^{234}Th reaching to 2–2.5 cm below the interface. There was a significant, seasonal variation in rates, with a warm-season average of $40 \times 10^{-8} \text{ cm}^2/\text{sec}$ and a cold-season average of $20 \times 10^{-8} \text{ cm}^2/\text{sec}$. ^{234}Th derived mixing rates were applied to Mn distributions through a mass balance model of Mn cycling. It was found that a particulate flux due to bioturbation, from the net dissolved Mn removal layer to a net dissolved Mn production layer adjacent to the interface, was as large as 38 percent of net dissolved Mn production. Mixing of particulate Fe sulfides may have a similar importance for Fe cycling.

Solute transport was estimated using measured $^{222}\text{Rn}/^{226}\text{Ra}$ disequilibrium. The pore water ^{222}Rn deficit could be explained using a model including vertical molecular diffusion and exchange with overlying seawater via exchange of pore water with bottom water in rapidly flushed burrows. Cores taken in all seasons could be split into three groups: (1) December through March -- the Rn deficit was explained by vertical molecular diffusion alone; (2) early summer (June) -- irrigation affected the ^{222}Rn profile to a depth of at least 20 cm; (3) late summer/fall -- irrigation was still important near the interface, affecting ^{222}Rn profiles to depths of 10–12 cm. ^{222}Rn

deficits were adequately explained by an exchange parameter (α) which decreased exponentially with the depth below the interface, but not by a constant- α model. Previous studies have explained irrigation using a constant exchange parameter throughout the irrigated layer. For comparative purposes, an α averaged over the upper 20 cm of the sediment column was calculated at the Buzzards Bay site; the range of depth-averaged α values found, $4\text{--}12 \times 10^{-7} \text{ sec}^{-1}$, is in agreement with values reported previously for a variety of nearshore sediments ($1\text{--}20 \times 10^{-7} \text{ sec}^{-1}$), using pore water SiO_2 as a tracer. ^{222}Rn -derived irrigation rates were applied to pore water Mn and Fe distributions. It was estimated that irrigation may contribute 20–40 percent of the dissolved Mn flux across the interface and about 20 percent of the dissolved Fe flux.

Study of pore water metal chemistry at the Buzzards Bay site included measurements of pore water Mn and Fe during all seasons and measurements of Co, Cu, and Ni in two cores (one under late winter conditions when the interface is most oxidizing, one when sulfate reduction was very important in the upper centimeter of the sediments). Fe regeneration sufficient to produce enrichments on water column particles was observed only during periods of summer and fall when the interface was reducing; otherwise, oxidation of Fe to insoluble Fe(III) limited Fe fluxes. Mn, Co, Cu, and Ni fluxes varied inversely to Fe fluxes; the primary control on fluxes of these elements was their limited solubility in reducing marine systems. The control was least important for Mn and Co; fluxes of Ni and Cu were significantly greater than zero only when sulfate reduction was unimportant in the upper centimeter of the sediment column. Fluxes of Mn were sufficient to affect the water column Mn distribution, with enrichments on water column particulates of up to 10,000 ppm inferred from calculated fluxes. Tentative estimates of the turnover time of dissolved Co, Cu, and Ni in the water column relative to the benthic flux indicated that the flux may be a significant contributor to the coastal Co cycle (turnover time = 1 yr), but is less likely to be important to Cu and Ni cycles (turnover times greater than 2 yrs).

In situ radiotracer migration experiments were carried out at the Buzzards Bay site. ^{54}Mn , ^{59}Fe , ^{60}Co , and ^{65}Ni were released into the sediments at depths ranging from 2.5 to 7 cm below the interface. The order of mobilities was $\text{Mn} \gg \text{Fe} > \text{Co}, \text{Ni}$, which is similar to the solubility trend for these metals in reducing marine systems. ^{63}Ni and ^{60}Co were essentially particle-bound in these exper-

iments; apparent diffusion coefficients calculated from their dispersion rates agreed with particle mixing rates from excess ^{234}Th distributions. Solid:solution distribution coefficients were calculated from ^{54}Mn dispersion and found to agree with directly measured values. The coefficient was approximately 15 (dpm/gm solid $\div$ dpm/gm pore water) in the upper 0.5 cm and below 5 cm, and 5–10 from 0.5 to 5 cm. Distribution coefficients for ^{59}Fe were approximately 120 below 0.5 cm. Although the trend of the distribution coefficients is clear, the quantitative results are only preliminary for the metal ion dispersion model when applied to the nonreactive tracer. ^{36}Cl could only explain a portion of the ^{36}Cl distribution. The agreement between calculated and directly measured ^{54}Mn distribution coefficients, as well as the way the distributions of tracers varied as a function of apparent diffusion coefficient and time, provides evidence in favor of the adequacy of the model used.

Supported by: NSF Grant OCE 82-16425
and NOAA, National Sea Grant
Program, Grant NA80-AA-D-
00077(R/P/7)

PRIMARY PRODUCTION OF PARTICULATE PROTEIN AMINO ACIDS: ALGAL PROTEIN METABOLISM AND ITS RELATIONSHIP TO THE COMPOSITION OF PARTICULATE ORGANIC MATTER

Steven E. Lohrenz

The biochemical and physiological bases underlying primary production of particulate protein amino acids were investigated in an effort to understand the relationship between algal protein metabolism and particulate organic matter composition.

In order to examine biochemical processes associated with conversion of inorganic carbon and nitrogen into protein, the effects of NH_4^+ limitation on free amino acid and protein composition and incorporation of inorganic ^{14}C were studied in the marine chlorophyte, Nannochloris sp. (clone GSB Nanno). Free amino acid metabolism was sensitive to changes in steady state NH_4^+ -limited growth rates. Reduced carbon and nitrogen flux into protein resulting from nitrogen limitation of growth was associated with reductions in proportions of cellular carbon and nitrogen in the intracellular free amino acid (IFAA) pool. Growth rate-dependent changes in IFAA pool composition reflected changes in rate limiting steps which were intermediate between assimilation of inorganic nitrogen and the incor-

poration of nitrogen into macromolecules. The proportion of cellular carbon in both protein and pools of free amino acids decreased with decreasing growth rate. Distributions of incorporated inorganic ^{14}C among free amino acids and protein provided qualitative descriptions of growth related compositional variations. Saturation rates of (IFAA) carbon with dissolved inorganic ^{14}C did not significantly change as growth rates decreased. In contrast, saturation rates of free glutamate, glycine + alanine, and valine did decrease with growth rate. At low growth rate, specific activities of the newly assimilated glutamate, valine, and glycine + alanine in protein were higher than specific activities of their corresponding free amino acid pools. This was likely a consequence of metabolic segregation and more rapid saturation of protein precursor pools.

Enrichment of NH_4^+ -limited steady state cultures of *Nannochloris* sp. with NH_4^+ led to a dramatic time dependent increase in free glutamine concentrations accompanied by differential increases in other free amino acids. Patterns of isotope incorporation into the free amino acids reflected real changes in concentrations. Increases were associated with the diversion of photosynthetically fixed carbon from lipophilic material towards amino acid biosynthesis and signaled the onset of increased protein synthesis. Preliminary investigations of two other marine phytoplankton species, *Dunaliella tertiolecta* (clone Dun) and *Thalassiosira weissflogii* (clone Actin), suggested that the nature and timing of the biochemical response to NH_4^+ enrichment is different among different species.

At high light intensity, increased NH_4^+ limitation of *Nannochloris* sp. was associated with decreases in cellular protein, protein to carbon ratios, and protein to chlorophyll α ratios. At low light intensities, cellular protein and protein to carbon ratios did not decrease with increasing NH_4^+ limitation. Chlorophyll α to protein ratios were generally higher at low light intensity and decreased with increasing NH_4^+ limitation, suggesting that nitrogen limitation suppressed low light enhancement of chlorophyll α production. Observed incorporation rates of inorganic ^{14}C exceeded predicted rates for glycine and alanine in protein under combined conditions of light and nitrogen limitation, an indication that protein turnover in excess of net synthesis was important under these conditions.

The characteristics of protein composition and incorporation of inorganic ^{14}C were examined in steady state NH_4^+ -

limited cultures of three other species of marine phytoplankton. The species studied included *Chaetoceros simplex* (clone BBSM), *Chattonella luteus* (clone Olisth), and *Chroomonas salina* (clone 3C). Saturation of protein precursors was different for different species and for different protein amino acids. *Nannochloris* sp. displayed the most rapid and complete equilibration, while *C. simplex* exhibited relatively slow or incomplete saturation and high sensitivity to nitrogen depletion. Intermediate patterns were observed for the other species. For all species examined, protein glycine and alanine demonstrated relatively rapid and complete equilibration of precursor pools and were least sensitive to nitrogen depletion.

With the knowledge that these selected amino acids consistently demonstrated relatively rapid and complete equilibration of precursor pools with ^{14}C -inorganic carbon in several taxonomically distinct marine algae, primary production of particulate protein amino acids and its relationship to the composition of particulate organic matter was investigated in the epilimnion of a semi-enclosed marine basin, Salt Pond, Mass. Studies were conducted previous to and throughout a major bloom of *Olisthodiscus magnus*. Before the bloom, the ratio of particulate protein amino acid (PPAA) production to particulate organic carbon (POC) production was not significantly different from the relative proportions of PPAA and POC in the particulate organic matter. Comparisons between estimated production and observed concentration changes indicated residence times of POC and PPAA were similar (10 - 20 days). Thus with respect to POC and PPAA, particulate organic matter composition reflected the composition of organic matter being produced by photoautotrophs. During the bloom decline, the PPAA/POC production ratio, a reflection of the activities of the metabolically active algal population, was significantly less than the PPAA/POC ratio of the particulate organic matter. This discrepancy can be attributed either to increased turnover of protein associated with the low inorganic nitrogen concentrations and in situ light intensities or selective removal of PPAA carbon by secondary transformational processes.

Supported by: The Andrew Mellon Foundation and NSF Grant OCE 82-15854.

THE GENETIC ANALYSIS OF THE VULVAL CELL
LINEAGES OF Caenorhabditis elegans

Edwin L. Ferguson, Jr.

The cell lineages of the nematode Caenorhabditis elegans are essentially invariant among individuals. We have begun an attempt to understand the genetic specification of one particular cell lineage, that of the hermaphrodite vulva. During vulval development, six equipotential cells of the ventral hypodermis respond to an inductive signal from the gonadal anchor cell to adopt one of three fates dependent upon position. Thus, the vulva is a model system to study the processes of induction and pattern formation at the level of individual cells.

We have isolated over 100 mutants, defining 26 genes that are abnormal in the vulval cell lineages. These mutants have one of two phenotypes: vulvaless hermaphrodites lacking a vulva and multivulva hermaphrodites with supernumerary pseudovulvae. Our analysis suggests that we may have identified most, or all, genes that can mutate to a multivulva or vulvaless phenotype.

We have constructed a genetic pathway of vulval development: three genes affect the production of vulval precursor cells; one gene affects the formation of the anchor cell; 15 genes are involved in the determination of the fates of the vulval precursor cells in response to the inductive signal; and three genes are necessary for the execution of the vulval cell fates.

Supported by: The National Institute
of Health Grants NIH-5-ROI-
GM24943-07 and GM 07287.

AN INVERSE METHOD FOR OBTAINING THE
ATTENUATION PROFILE AND SMALL VARIATIONS
IN THE SOUND SPEED AND DENSITY PROFILES
OF THE OCEAN BOTTOM

Subramaniam D. Rajan

The acoustic properties of marine sediments have a direct effect on the propagation of sound in the ocean. In the frequency range of interest (50-500 Hz), the sediment can be modelled as a fluid. Assuming horizontal stratification of the ocean bottom, the acoustic parameters of interest are the compressional wave speed, the compressional wave attenuation, and density as a function of depth.

An inverse method based on a perturbation technique is presented in this thesis for the determination of these parameters. A monochromatic source experiment is proposed because of the desirability of such

an experiment for determining the acoustic properties of an anelastic medium. The input information is the plane wave reflection coefficient as a function of the angle of incidence at a fixed frequency. A nonlinear integral equation relating the variations of these acoustic properties from a known reference value to the plane wave reflection coefficient is derived. This is then linearized using the Born approximation. The region of validity of the Born approximation is derived and based on the optimum angular aperture for the input data.

The linearized integral equation is a Fredholm integral equation of the first kind. An acceptable stable solution of the integral equation is obtained by imposing a priori constraints on the solution. The inversion method is tested using synthetic data and inversions are carried out for various examples of the attenuation coefficient profile and the sound speed profile. The results obtained with noise free data show good agreement between the true profiles and the reconstructed profiles. The resolution obtainable with the data set is studied using the resolving power theory of Backus and Gilbert, and the inversion method is shown to provide adequate resolution. The effect of additive noise in data is examined, and inversions performed with noisy data yielded stable acceptable results.

Supported by: ONR Contract
N00014-82-C-0152.

ESTIMATION OF PLANETARY WAVE PARAMETERS
FROM THE DATA OF THE 1981 OCEAN ACOUSTIC
TOMOGRAPHY EXPERIMENT

Ching-Sang Chiu

Using the maximum-likelihood estimation method and minimization techniques, quasi-geostrophic wave solutions were fitted to the observations of the 1981 Ocean Acoustic Tomography Experiment. The experiment occupied a 300 km square area centered at 26°N, 70°W, and had a duration of ~80 days. The data set consisted of acoustic travel-time records, temperature records, and CTD profiles, obtained from the acoustic tomographic array, moored temperature sensors and recorders, and ship surveys, respectively. While the latter two were conventional spot measurements, the former corresponds to integral measurements of the temperature (or sound-speed) field.

The optimal fit to the data corresponded to 3 waves in the first baroclinic mode, evolving under the presence of a westward mean flow with vertical shear. The flow

was estimated to be weak (~ 2 cm/s), but it changed the wave periods significantly by producing large Doppler shifts. The waves were dynamically stable to the mean flow, had weak nonlinear interactions with each other, and did not form a resonant triad; thus, they constituted a fully linear solution.

Evidence for the existence of the waves was strongly supported by the high correlation (~ 0.9) between the data and the fit, the large amount of signal energy resolved (~ 80 percent), the excellent quality of the wave-parameter estimate (only about 10 percent in error), and the general agreement between the observations and quasi-geostrophic linear dynamics.

Supported by: ONR Contract
N00014-82-C0019.

FEEDING HABITS OF THE YELLOWTAIL FLOUNDER AND PRODUCTION OF ITS INVERTEBRATE PREY ON GEORGES BANK

Jeremy S. Collie

As part of the Georges Bank Benthic Infauna Monitoring Program, size-frequency analysis was used to study the life history and production of three benthic amphipod species: Ampelisca agassizi, Unciola inermis and Erichthonius fasciatus. Abundant over large areas of Georges Bank, these amphipods are important prey of yellowtail flounder. From benthic grab samples collected quarterly during 1981 to 1983, over 200 individuals of each species were measured for each sampling date. The computer program NORMSEP separated the length-frequency distributions into cohorts. Growth and mortality rates were determined by following cohorts through time; production was calculated as the sum of growth increments. Differences in the population dynamics of the three species were exemplified by annual production-to-biomass ratios (P/B). E. fasciatus had the highest P/B (2.8 to 4.1), followed by U. inermis (1.3 to 2.7) and A. agassizi (1.3 to 1.4). These results, the first direct production estimates for benthic macrofaunal species on Georges Bank, are compared to production estimates for other marine amphipod species. Amphipod production rates on Georges Bank are as high as production rates of related near-shore species with similar life-spans.

The Northeast Fisheries Center sampled yellowtail flounder stomachs at three sites on four quarterly dates from August 1982 to May 1983. As closely as possible, stomach sampling coincided with the dates and locations of benthic monitoring to enable direct comparison between ingested

and available food. Stomach contents were sorted and weighed and important prey species were measured. Yellowtail flounder feed mainly on benthic macrofauna; amphipods and polychaetes are the most important prey groups. Although the diet composition varied among stations and dates, in each case a few prey species constituted the bulk of the diet. Selection indices were calculated to compare the species composition of the stomach contents to that of the benthic macrofauna. Food selection by yellowtail flounder is explained on the basis of prey life history and prey size. The species and size-selection indices account for most of the variability in diet composition. A log-normal curve was fit, by least squares, to the size-selection indices. According to this fit, the optimum prey weight for yellowtail flounder is 21 mg.

The rate of food consumption by yellowtail flounder was calculated by two methods. The bioenergetic method sums the food required to satisfy the energetic requirements of the fish. The second method is based on the weight of stomach contents and the rate of food evacuation from the stomach. The bioenergetic method gave consistently higher results (1.4 to 1.6 kg fish⁻¹yr⁻¹) than the stomach-content method (0.5 to 0.8 kg fish⁻¹yr⁻¹). Yellowtail flounder abundance was estimated by a method that uses the commercial catch data to standardize the survey, relative-abundance index. These abundance estimates were divided by the appropriate areas to obtain yellowtail flounder density estimates for fall 1982 of 20.0 and 41.3 fish per hectare for Georges Bank and Southern New England, respectively. Consumption rates per fish were multiplied by flounder density to obtain estimates of consumption per unit area, which range from 1.2 to 6.3 gww m⁻² yr⁻¹. Annual production of six important prey species was calculated. Yellowtail flounder consumption as a percentage of prey production was 6 to 12 percent, 2 to 5 percent, and 1 to 3 percent, for the amphipods Unciola inermis, Erichthonius fasciatus, and Ampelisca agassizi, respectively; 11 to 34 percent and 7 to 21 percent for the polychaetes Chone infundibuliformis and Nephtys incisa, respectively; and less than 1 percent for the sand dollar Echinarachnius parma.

Supported by: DoE Minerals Management
Service Contract 14-12-0001-29192.

AUTHOR INDEX

	Page No.		Page No.
Abrahamsson, Bernhard	MP-3	Capuzzo, Judith M.	B-7,15,26
Akens, John J.	OE-8	Carey, Francis G.	B-3
Allen, Julie	GG-12	Caron, David A.	B-20,21
Altabet, Mark A.	C-3	Casey, J. F.	GG-5
Anderson, Donald M.	B-12,18,19,22,23	Casey, John G.	B-3
Anderson, O. Ketil	B-21	Caswell, Hal	B-25
Anger, K.	B-26	Cessi, Paola*	PO-12
Anger, V.	B-26	Cetta, Catherine M.	B-28
Aubrey, David G.	GG-3,4,5,11,23,25	Chapman, David C.	PO-3,4,17
Aubry, Marie-Pierre	GG-3,7,19	Chapnick, S. D.	C-10
Backus, Richard H.	B-29;OE-10	Chausse, Dolores H.	PO-17
Bacon, Michael P.	C-8,9,10,16	Chave, A. D.	GG-13
Baggeroer, Arthur B.	OE-10	Child, C. Allan	B-28
Ballard, Robert D.	C-15,17;OE-13,14	Chiu, Ching-Sang*	OE-11;GS-9
Barber, Valerie	B-29;OE-10	Chu, Ka Hou	B-4
Barbour, R. Lorraine	PO-19	Churchill, James H.	PO-4,11
Barth, John A.	PO-4	Cicin-Sain, Biliana	MP-4
Bastian, Robert K.	B-15	Ciesluk, Alfred J.	PO-17
Beardsley, Robert C.	PO-4,5	Clifford, C. H.	C-4
Behringer, D.	OE-10	Cole, J. J.	C-10
Belkin, Shimshon	B-16	Collie, Jeremy S.*	GS-10
Benavides, Livia M.	C-3,8	Constable, Steven C.	GG-13,16
Bennett, Sara L.*	PO-15	Conte, M.	B-26
Berg, Carl J. Jr.	B-10	Converse, Christopher H.	OE-9
Berggren, W. A.	GG-3,19	Cook, H.	GG-24
Berteaux, H. O.	OE-8	Corliss, Bruce H.	GG-18;PO-8
Biesiot, Patricia*	B-7	Cornillon, Peter C.	PO-11,16,17
Billings, John D.	GG-26	Cornuelle, B.	OE-10
Binder, Robert L.	B-3	Coughanowr, C. A.	GG-24
Binkley, Kandace	C-13	Cowles, T. J.	OE-10
Bird, J. D.	OE-8	Cox, C. S.	GG-13
Birdsall, T.	OE-10	Craddock, James E.	B-29;OE-10
Bishop, J. K. B.	B-26,29	Crane, K.	GG-5
Block, Barbara A.	B-3	Crone, Martie J.	B-13
Blough, Neil V.	C-10	Csanady, Gabriel T.	PO-7,15
Bock, Eberhard	B-17	Cucci, Terry L.	B-24
Boehm, Paul D.	C-16	Cycon, Dean E.	MP-4,5,6
Bonatti, E.	GG-5	Dacey, John W. H.	B-12
Bonde, L. W.	OE-8	Davis, A. C.	C-4
Bonneau, Roland	C-18	Davis, L. H.	B-24
Bowin, Carl	GG-11,12	Davis, Russ E.	PO-17
Boyle, E. A.	C-10;GG-17	de Kroon, Hans	B-25
Bradley, Albert M.	B-29;OE-10	Dennett, Mark R.	B-21,22
Bradshaw, Alvin L.	PO-6	Desaubies, Yves	OE-11
Breitinger, I.	C-12	DeSilvestre, Ingrid	MP-17
Brewer, Peter G.	C-16	Detrick, Robert S.	GG-14
Brink, Kenneth H.	PO-3,4,17	Deuser, Werner G.	C-3,10,12,13,14,15
Briscoe, Melbourne G.	PO-17,19	Dick, Henry J. B.	GG-22
Broadus, James M.	MP-3,4,11	Dillon, W. P.	GG-4
Brocher, Thomas M.	GG-12,13,14,16	Doering, Peter H.	C-17,18
Brown, M.	OE-10	Doutt, James A.	OE-11
Brownawell, Bruce J.	C-3,4	Druffel, Ellen R. M.	C-3,6,8,11
Bryan, W. B.	C-17;GG-21	Duckworth, Gregory L.	OE-10
Bryant, R. J.	GG-24	Dunworth, Jane A.	PO-19
Bucklin, Ann	B-27	Ebinger, Cynthia J.*	GG-9
Buesseler, Ken Q.*	C-8	Edmond, J. M.	OE-9
Buhl, P.	GG-16	Ehrmann, Lisa M.	GG-17
Burton, Christine	C-18	Eichenberg, Timothy	MP-6
Butler, Rhett	GG-13	Ellis, J. P.	GG-23
Butman, Cheryl Ann	OE-4,5	Elthon, D.	GG-5
Canuel, Elizabeth A.	C-7,17,18	Emery, K. O.	GG-3,4,5,18

Erlank, Anthony J. GG-22
 Ewing, J. I. GG-12
 Fairbanks, Richard G. PO-4
 Farmer, Mary W. B-10
 Farrington, John W. B-8;C-3,4,11
 Federiuk, Joyce M. PO-12
 Fenwick, Judith MP-17
 Ferguson, Edwin L. Jr.* GS-9
 Fischer, Karen M.* GG-13
 Flagg, Charles N. PO-5
 Flierl, G. R. OE-10
 Fornari, D. J. GG-5
 Fox, P. J. GG-5,7
 Franks, Diana G. B-17
 Frazer, Nat B. MP-6,7,8
 Frey, Fred A. GG-21,22
 Frisk, George V. OE-11
 Fry, Virginia A.* GG-10
 Fucile, Paul D. OE-9
 Gagosian, Robert B. C-11
 Gaines, Arthur G. MP-9
 Gallagher, Scott M. B-5,6
 Gallo, D. G. GG-5
 Galloway, W. C-4
 Garcon, Veronique C. B-12
 Gardner, Wilford D. GG-6
 Gelboin, Harry V. B-9
 Gilmer, Ronald B-28,29
 Glibert, Patricia M. B-19,23
 Goddard, D. A. C-12
 Goldman, Joel C. B-20,21,22
 Goud, Margaret R.* GG-6
 Grant, B. OE-9
 Grant, William D. OE-5,6
 Grassle, J. Frederick B-9
 Griffin, S. M. C-11
 Groman, Robert C. OE-9
 Gross, Thomas F. OE-7
 Guest, Brian J. PO-17
 Haidvogel, Dale B. PO-4
 Hall, Melinda M.* PO-9,13;GS-5
 Hamlyn, P. GG-5
 Hamuro, K. C-17
 Harbison, G. Richard B-10,12,28,29
 Harris, Stewart E. OE-7
 Hart, Stan R. GG-22
 Hayes, Stanley P. PO-10
 Hayon, E. C-19
 Hays, Earl E. OE-11
 Healey, Michael C. MP-9
 Heinmiller, R. OE-10
 Hemleben, C. C-12
 Henrichs, Susan M. C-4
 Hicke, Linda A. C-6
 Hicks, Randall E. C-5
 Hoagland, Porter III MP-10
 Hogg, Nelson G. PO-6
 Holland, William R. PO-9,12
 Hollister, Charles D. GG-6
 Honjo, S. C-11
 Horan, P. K. B-24
 Howarth, Robert C-18
 Howe, B. M. OE-13
 Howes, Brian L. B-12

Huh, C.-A. C-8,9
 Hunt, John M. C-13
 Jacobson, Dean M. B-22
 Jaffe, Jules S. OE-3,4,7
 James, Margaret O. B-8
 Jannasch, Holger W. B-16,17,18
 Jansa, L. F. GG-4
 Janssen, John B-12
 Jenkins, William J. C-13
 Johnson, David A. GG-19
 Jones, E. J. W. C-12
 Joyce, Terrence M. PO-8,9,19
 Kamenkovich, Vladimir M. PO-11
 Kaminski, Michael A.* GG-7
 Kana, Todd M. B-23
 Karson, Jeffrey A. GG-5,6,7
 Kase, Rolf H. PO-10
 Keafer, Bruce A. B-19
 Keffer, Thomas PO-8
 Keigwin, Lloyd D. Jr. GG-7,17,18
 Kent, D. V. GG-7
 Kidd, W. S. F. GG-5
 Kinder, Thomas H. PO-4
 King, Gary M. B-12
 King, Lauriston MP-18
 Klein, J. Patrice PO-13
 Klitgord, Kim D. GG-8
 Kloepper-Sams, Pamela J.* B-8,9
 Knap, Anthony H. C-13
 Knapp, George P. PO-18
 Knox, R. OE-10
 Kong, L. GG-14
 Kraus, Scott D. B-13
 Kremer, Patricia B-28
 Kurz, Mark D. C-14
 Ladner, Rosamund C. MP-8
 Lalou, C. C-14
 Landrum, R. S. GG-4
 Laursen, Finn MP-11
 Lawrence, J. R. C-14
 Lazarus, David GG-20,21
 Lech, John J. B-3
 Lee, Cindy C-5,6,10,18
 le Roex, Anton GG-22
 Leschine, Thomas M. MP-11
 Levy, Ellen PO-18
 Li, Y.-H. C-14
 Liang, Gao GG-18
 Libes, S. M. C-14,15
 Limeburner, Richard PO-18
 Livingston, Hugh D. C-8,9
 Livramento, J. B. C-4
 Lobel, Phillip S. B-29
 Lohrenz, Steven E.* GS-7
 Luyten, James R. PO-14
 Lyne, Vincent D. PO-5
 Madin, Laurence P. B-28
 Madsen, Ole Secher OE-6,7
 Malmgren, Bjorn A. GG-7
 Malod, Jacques A. GG-8
 Manganini, Steven J. GG-26
 Mangum, Linda J. PO-10
 Manheim, F. T. GG-4
 Mann, Roger B-5,6

Marcus, Nancy H. B-23
 Marinucci, Andrew C. C-5
 Marquette, Craig D. PO-17
 Marra, John B-29
 Martin, William R.* GS-6
 Martinson, Douglas G. PO-8
 Matsuda, Jun-Ichi GG-14
 McAlister, V. L. B-29
 McCave, I. N. GG-8,24
 McConachy, T. F. C-15;OE-14
 McCormick, Stephen D. B-11
 McCosker, John E. B-3
 McCoy, Floyd W. GG-10
 McCreary, Scott MP-12
 McDowell, Donald M. B-11
 McElroy, Anne E.* B-6;GS-3
 McKenzie, Judith A. C-6
 McNutt, Marcia K. GG-13,14
 Measures, C. I. OE-9
 Melson, W. G. C-17
 Meo, Mark MP-12,18
 Mercier, Richard S.* GS-4
 Metzger, K. OE-10
 Milkowski, George W. PO-11
 Millan, Victor MP-13
 Miller, James OE-11
 Milliman, J. D. GG-23
 Mok, Henry Y. C-6
 Monaham, Edward C. PO-15
 Monin, Andrei S. PO-11
 Montgomery, Ellyn T. PO-19
 Montgomery, W. Linn B-11
 Moody, R. H. GG-5
 Moore, Karen E. B-13,15
 Morin, Roderick B-11
 Morris, Michael A. MP-12,13
 Morton, Alfred W. B-29;OE-10
 Mottl, M. J. C-14,15;OE-14
 Mountain, Gregory S. C-16
 Muench, Robin D. PO-3
 Muirhead, K. B-24
 Munk, W. OE-10
 Naiman, Robert J. B-11
 Needham, D. GG-5
 Nelson, Douglas C. B-16
 Newman, James B. OE-13
 Nigrini, Catherine A. GG-19
 Nosenchuck, D. M. B-23
 Nowell, Arthur R. M. OE-7
 Okada, H. C-12
 O'Muircheartaigh, Iognaid G. PO-15
 Oremland, Ronald C-18
 Palmason, G. GG-4
 Palmer, D. R. C-15
 Park, Sang S. B-9
 Pedlosky, Joseph PO-12,13,14
 Perez, Efrain MP-9
 Peterson, M. J. MP-14,15,16
 Pfirmman, Stephanie L.* GS-3
 Phelps, D. K. C-4
 Phinney, D. A. B-24
 Pierce, Stephen D. PO-9
 Plaisier, Anton B-25
 Povia, Danielle N. GG-26

Pratt, Harold L. B-3
 Prescott, John H. B-13
 Price, Carol A. B-13
 Price, James F. PO-10,12,16,17
 Purdy, G. M. GG-14;OE-8
 Rajan, Subramaniam D.* GS-9
 Rampone, William M. C-6
 Randall, John E. B-29
 Reid, Arch M. GG-22
 Requejo, A. G. C-16
 Reynolds, G. T. B-23
 Rial, Jose A. GG-13
 Richardson, James I. MP-8
 Richardson, Philip L. PO-10,18,19
 Richter, Charles F. GG-13
 Roman, M. R. B-26
 Rona, P. A. C-14,15
 Rosenbaum, J. C-14
 Ross, David A. GG-9;MP-16,17
 Sartori, R. GG-5
 Sasaki, Glenn C. B-7
 Sato, Tomamasa OE-4
 Sayles, Frederick L. C-16
 Scheer, Edward GG-12
 Scheltema, Amelie H. B-10
 Schevill, William E. B-13
 Schleicher, Karl E. PO-6
 Schlosser, Ursula B-17
 Schmitt, Raymond W. OE-9
 Schmitz, William J. Jr. PO-9,12
 Schouten, Hans GG-8
 Scranton, Mary I. C-16
 Shaw, Peter R. GG-15
 Shen, G. T. C-10
 Sherr, Evelyn B. C-8
 Sholkovitz, Edward R. C-8
 Shure, Loren GG-13,14
 Silva, Maynard E. MP-4,17,18
 Slotine, Jean-Jacques E. OE-13
 Smith, M. Estellie MP-18
 Smith, Richard C-18
 Smith, Woolcott GG-12
 Southard, John B. GG-6
 Spiesberger, J. OE-10
 Spindel, Robert C. OE-10,11,12,13
 Spindler, M. C-12
 Squires, Robert OE-7
 Stage, Steven A. PO-16
 Stalcup, Marvel C. PO-19
 Stegeman, John J. B-3,7,8,9
 Stephen, R. A. GG-14,15
 Stoecker, Diane K. B-24
 Stolzenbach, Keith D. B-12,19;OE-5
 Stommel, Henry M. PO-14,18
 Storch, V. B-26
 Stramma, Lothar PO-16,17
 Stroup, J. B. GG-5
 Sturm, Michael C-6
 Sunda, W. G. B-24
 Swift, Stephen A. GG-9
 Takahashi, Kozo GG-24,25,26
 Talley, Lynne D. PO-8
 Tarafa, Martha E. C-7,8,16,18
 Tarbell, Susan A. PO-19

Page No.

Taviani, M.	C-14
Teal, John M.	B-15
ten Brink, U. S.	GG-16
Thompson, G.	C-12,14,17
Toole, John M.	PO-10
Tripp, B. W.	C-4
True, Mary B.	C-17,19
Tucholke, Brian E.	GG-4,8,9,10
Tupper, George H.	PO-17
Tuttle, Jon H.	B-18
Tyack, Peter	B-13,15
Uchupi, Elazar	GG-9
Urquhart, David	B-3
Valois, Frederica W.	B-17
van Groenenendael, Jan	B-25
Vaulot, Daniel*	GS-4
Von Damm, K. L.	OE-9
von der Heydt, Keith	OE-10
Von Herzen, R. P.	C-15;GG-14;OE-14
Voorhis, Arthur D.	PO-11
Wakeham, Stuart G.	C-7,17,18
Walden, B.	OE-9
Walden, R. G.	OE-8
Walsh, David	PO-10
Walton, A. J.	B-23
Wang, Ying	GG-11
Warren, Bruce A.	PO-8
Waterbury, John B.	B-17,24
Watkins, William A.	B-13,14,15
Watson, Stanley W.	B-17
Watts, A. B.	GG-16
Watts, Jennifer L.	B-23
Webb, D.	OE-10
Webb, Spahr C.	GG-13,16
Weinberg, James R.	B-25
Weinstein, E.	OE-4
Weiss, A. J.	OE-4
Weiss, R. F.	OE-9
Weller, Robert A.	PO-16,17
Westall, John	C-11
Whelan, Jean K.	C-7,8,16,18
White, Robert S.	GG-9
Whitehead, John A. Jr.	PO-4,7
Whitlatch, Robert B.	B-25
Wiebe, Peter H.	B-26,27,29;OE-10
Willey, Joanne M.*	B-17
Williams, Albert J. III	OE-9
Winn, Howard E.	B-13
Wirsen, Carl O.	B-16,17,18
Witzell, W.	OE-8
Wong, C. S.	C-11
Wood, A. Michelle	B-24
Woodin, Bruce R.	B-9
Wooding, Christine M.	PO-19
Worcester, P.	OE-10,13
Wunsch, Carl I.	OE-10,PO-9
Yentsch, Clarice M.	B-24
Yoerger, Dana R.	OE-13
Zafirliou, Oliver C.	C-10,17,18,19
Zenk, Walter	PO-10

* student