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Doel W. Spencer

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PREFACE

This Summary of Abstracts contains all abstracts submitted for publication during calendar year 1981 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 Because some of the abstracts may not be published in the journal to which they have been submitted initially, we have purposely omitted identifying the journals.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, reading "Derek W. Spencer", is written over a horizontal line.

Derek W. Spencer

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DEPARTMENT OF BIOLOGY

George D. Grice, Department Chairman

BIOLOGY

ANIMAL PHYSIOLOGY

CRUSTACEAN BIOENERGETICS: THE ROLE OF ENVIRONMENTAL VARIABLES AND DIETARY LEVELS OF MACRONUTRIENTS ON ENERGETIC EFFICIENCIES

Judith M. Capuzzo

Aquaculturists have been interested in the nutrition and growth of commercially important crustacean species in their attempts to define suitable methods for mass cultivation. Much research has been devoted to developing suitable diets, defining nutritional requirements and establishing optimal culture conditions. Crucial to optimization of crustacean growth is an understanding of energy partitioning and metabolic utilization of various dietary constituents by crustacean species. Metabolic responses of an organism to various components of its diet are important determinants of the physiological processing of calories and nutrients and may provide an index of the efficiency of energy utilization of a specific diet. Studies dealing with the effects of diet on growth and energetic efficiencies of various crustacean species are reviewed, with particular emphasis on several species of Homarus, Macrobrachium and Penaeus.

Utilization of a dietary component for energy needs is affected by the dietary level, the organism's ability to catabolize that substrate and the availability of other dietary constituents as sources of energy. Protein utilization and the protein sparing action of dietary lipid and carbohydrate have been investigated for several species of crustaceans. Decreased rates of protein catabolism and increased protein efficiency ratios were observed in Homarus and Macrobrachium fed diets with lipid and/or carbohydrate levels as energy supplements. Studies with Penaeus have indicated that utilization of protein and definition of optimum protein levels can only be evaluated in relationship to the total energy content of a diet. Other dietary constituents that have been shown to have a significant impact on energetic efficiencies include essential fatty acids and fiber (cellulose) content. The comparative bioenergetic aspects of crustacean nutrition are discussed.

In press: Proceedings, Second International Conference on Aquaculture Nutrition.

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NUTRITION IN THE TEREDINIDAE

Roger Mann

The teredinidae are unusual among the marine bivalve molluscs in that the adult form bores into, ingests and digests wood in the marine environment. They are equipped with rasping valves, digestive diverticula specialized for wood digestion and, with the exception of Kuphus, a wood storing caecum. The cellulose structure of wood provides a dietary carbohydrate source following cellulolytic activity. The origin (endogenous or exogenous) and site of function of the celluloses responsible for wood degradation are still a subject of discussion. Wood is low in nitrogen content. The dietary nitrogen requirement of the adult teredinid is probably fulfilled from a combination of sources including phytoplankton and bacteria retained during filter feeding, dissolved organic material (DOM) and dissolved inorganic nitrogen (DIN). DIN utilization appears to be related to the presence of symbiotic bacteria in the Gland of Deshayes in the teredinid gill. These microaerophilic bacteria are capable of both fixing nitrogen and producing enzymes which degrade cellulose, and probably play a significant role in both nitrogen and carbohydrate metabolism in their host.

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

INFLUENCE OF ESTRADIOL AND TESTOSTERONE ON HEPATIC AND RENAL MONOOXYGENASE SYSTEMS IN IMMATURE BROOK TROUT, Salvelinus fontinalis

Ana M. Pajor and John J. Stegeman

The steroid hormones estradiol-17B and testosterone administered to immature brook trout produced a variety of responses in hepatic and renal microsomal enzymes. Estradiol treatment resulted in an increased hepatosomatic index in both sexes. Male fish treated with either steroid showed a decreased gonadosomatic index. Levels of hepatic microsomal cytochrome P-450 were elevated by testosterone and depressed by estradiol in both males and females. SDS-polyacrylamide gel electrophoresis of hepatic microsomes revealed that estradiol treatment of either sex resulted in loss of several proteins including some at 56,000 daltons, possibly containing cytochrome P-450. Levels of both NADPH-cytochrome c reductase and NADH-cytochrome c reductase activity in liver microsomes were increased by testosterone, but not estradiol. In kidney microsomes the levels of cytochrome P-450 and NADH-cytochrome c reductase activity

were unaffected by steroid treatment, but NADPH-cytochrome c reductase activity was depressed by both estradiol and testosterone. Hepatic microsomal benzo[a]pyrene monooxygenase and ethoxyresorufin O-deethylase activities and the response to 7,8-benzoflavone in vitro were affected little by steroid treatment. The steroid effects on cytochrome P-450 in liver probably involves regulation of forms that function in hormone metabolism. Whether factors additional to steroids may be involved in this regulation of hepatic cytochromes P-450 in fish is uncertain.

Supported by: NSF Grant OCE77-24517.

A FEASIBILITY STUDY OF MICROENCAPSULATED FEEDS FOR LARVAL FISH

Glenn C. Sasaki

The often rapid disintegration of artificial feeds in water has discouraged the formulation of such feeds for larval marine fish which require small food particle sizes. A microencapsulated feed, a carboxymethylcellulose (CMC) bound feed, and live *Artemia* nauplii were compared for rate of leaching and protein, carbohydrate and lipid retention. These feeds were fed to *Fundulus heteroclitus* larvae and the apparent assimilation efficiencies and growth promoting abilities of each feed measured. *Artemia* nauplii supported both the fastest growth and highest apparent assimilation efficiency. An intermediate apparent assimilation efficiency but no growth was recorded with the bound food. This may be related to the CMC bound feed's high leaching rate and the concomitant decrease in water quality. The micro-encapsulated feed did support initial growth, although a lower apparent assimilation efficiency was evident. Leaching from the microencapsulated feed was high during its preparation, but no further leaching occurred during feeding. Microencapsulated diets have potential as larval fish feed, and also may be useful as a method for nutritional and toxicological studies.

Supported by: NOAA Sea Grants NA79AA-D-00102 and NA80AA-D-00077.

CYTOCHROME P-450 AND MONOOXYGENASE ACTIVITY IN CARDIAC MICROSOMES FROM THE FISH *Stenotomus chrysops*

John J. Stegeman, Bruce R. Woodin,
Alan V. Klotz, Richard E. Wolke
and Nanette R. Orme-Johnson

Optical spectroscopy of dithionite- or NADPH-reduced, CO-treated microsomes

(having little mitochondrial contamination) indicated the presence of cytochrome P-450 with an absorption maximum near 447 nm in both ventricle and atrium from the heart of the marine fish scup (*Stenotomus chrysops*). Further, low temperature (ca. 14 K) EPR spectra of microsomes from ventricle and atrium had resonances with g values near 2.42, 2.26 and 1.91, typical of low spin cytochromes P-450. Average values for the specific P-450 content of these microsomes were 0.18 nmol/mg in ventricle and 0.25 nmol/mg in atrium, but large variation was observed. In contrast to muscular parts of the heart, the specific P-450 content in bulbus arteriosus (aorta) microsomes was very low (0.003 nmol/mg) and the wavelength of the reduced-CO absorption maximum was like that in liver microsomes. The levels of CO-inhibitable benzo[a]pyrene (BP) monooxygenase, 7-ethoxyresorufin O-deethylase and aminopyrine N-demethylase activities per nmol P-450 were 10-30 times lower in cardiac microsomes than in liver microsomes. Treatment with 3-methylcholanthrene produced an insignificant change in BP monooxygenase activity, yet the metabolism of BP was strongly inhibited by 7,8-benzoflavone in cardiac microsomes from either control or treated animals. Microsomes from both ventricle and atrium metabolized BP with pronounced regio-specificity. More than 60 percent of the total metabolites were 7,8- and 9,10- (benzo-ring) dihydrodiols, while 4,5- (K-region) dihydrodiol was undetectable. Whether the low catalytic activities with the xenobiotics seen here are associated with major or minor (constitutive or induced) forms of the cardiac microsomal cytochrome P-450 is not yet known, but the results are consistent with the idea that other, undefined functions may be the principal ones of this hemoprotein in microsomes from fish and possibly mammalian heart.

In press: Molecular Pharmacology.

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HEPATIC MICROSOMAL MONOOXYGENASE ACTIVITY AND THE BIOTRANSFORMATION OF HYDROCARBONS IN DEEP BENTHIC FISH FROM THE WESTERN NORTH ATLANTIC

John J. Stegeman

Microsomal electron transfer-components cytochrome P-450, cytochrome b₅, NADPH-cytochrome c (P-450) reductase activity and NADH-cytochrome c (b₅) reductase activity were present in hepatic microsomes from several species of deep sea

fishes sampled between 1,400 and 3,200 meters deep in the North Atlantic. The specific content of cytochrome P-450 varied among the species but was within the range observed for shallow water fish species. The specific content was highest in the deepest sampled species, Coryphaenoides armatus (0.25 nmol/mg microsomal protein). Hepatic microsomes from this species also exhibited little or no putative cytochrome P-420 whose presence suggested degradation of cytochrome P-450 in the other species. Ethoxyresorufin O-deethylase and benzo(a)pyrene hydroxylase activities were high in several species, particularly Coryphaenoides armatus. Strong inhibition of benzo(a)pyrene hydroxylase activity by α -naphthoflavone was demonstrated in some species. The data suggest that some hepatic cytochrome P-450 in Coryphaenoides armatus (and possibly Coryphaenoides teptolepis and Bathysaurus mollis) but not in Coryphaenoides rupestris or Antimora rostrata may have been induced by environmental chemicals in the deep sea. As in other teleosts, Coryphaenoides hepatic microsomes metabolized benzo(a)pyrene in vitro with a high specificity for the benzo-ring, suggesting the capacity to efficiently form mutagenic derivatives of some hydrocarbons.

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INDUCTION OF HEPATIC CYTOCHROME P-450 IN FISH AND THE INDICATION OF ENVIRONMENTAL INDUCTION IN SCUP (Stenotomus chrysops)

John J. Stegeman, Alan V. Klotz,
Bruce R. Woodin and Ana M. Pajor

The responses of liver microsomal monooxygenases in three teleost species, croaker (Micropogon undulatus), rainbow trout (Salmo gairdneri) and scup (Stenotomus chrysops) to polynuclear aromatic hydrocarbon (PAH) inducers were compared. In all three species PAH induced higher rates of ethoxyresorufin and/or benzo[a]pyrene (BP) metabolism and levels of cytochrome P-450, but the species differed in some other responses. The induction of P-450 appears to be associated with the synthesis of new (or additional) microsomal protein at 57,000 daltons in trout and 54,000 daltons in scup, identifiable by SDS-polyacrylamide gel electrophoresis. Further data suggest that ethoxyresorufin metabolism in scup may be catalyzed by a minor form of P-450 distinct from the major induced protein. All scup examined thus far from natural populations exhibit properties of hepatic microsomes characteristically associated with the induced state. BP is metabolized by control and untreated scup with a high regiospecificity normally associated with

the production of reactive and mutagenic metabolites, which may have implications for animals in the field.

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THE REPRODUCTIVE CYCLE OF THE BAY SCALLOP Argopecten irradians irradians (LAMARCK) IN A SMALL COASTAL EMBAYMENT ON CAPE COD, MASSACHUSETTS

Rodman E. Taylor and Judith M. Capuzzo

The spawning activity of the bay scallop Argopecten irradians irradians (Lamarck) was monitored from May through September in a small embayment on Cape Cod, Massachusetts, and correlated with changes in hydrographic conditions. Spawning activity of bay scallops began in May and continued through July with some minor activity occurring during August and September; activity was most closely related to changes in ambient temperature and occurred predominantly before the summer maximum temperature was recorded. As temperatures declined in the late summer and early fall, increased gametogenic activity was evident. A longer period of spawning activity was observed than was previously reported for New England waters.

Supported by: NOAA Sea Grant NA80AA-D-00077 (R/A-12).

A Q U A C U L T U R E

CHANGES IN AGAR AND OTHER CHEMICAL CONSTITUENTS OF THE SEAWEED, Gracilaria tikvahiae, WHEN USED AS A SUBSTRATE IN METHANE DIGESTERS

Kimon T. Bird, M. Dennis Hanisak and John H. Ryther

The feasibility of recovering agar after the methanogenic digestion of the agarophyte, Gracilaria tikvahiae, was investigated in two experiments. The data indicate that during the breakdown of this seaweed in digesters, agar is an important carbon source. The changes in the chemical constituents of the seaweed with increased digestion time suggest that digestion proceeds through the initial hydrolysis of the agar into simpler oligosaccharides. The parameters of commercial agar quality and the total amount of agar in the digester

rapidly decline with time, indicating that recovery of agar from seaweed digesters is impractical. The solid fractions of both the digester residues and the agar extraction residues appear to be composed primarily of cellulose, which is not readily fermentable to biogas.

In press: Resource, Recovery and Conservation.

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LARVAL AND EARLY POST-LARVAL DEVELOPMENT OF THE OCEAN QUAHOG, Arctica islandica

Richard A. Lutz, Roger Mann,
Joy G. Goodsell and Michael Castagna

Mature eggs were stripped from ripe adult specimens of Arctica islandica and exposed to a dilute solution of ammonium hydroxide for various lengths of time prior to addition of stripped sperm. Larval and early post-larval stages were cultured under experimental laboratory conditions using standard bivalve rearing techniques. Larval cultures were maintained at various controlled temperatures ranging from 8.5° to 14.5°C. Minimum time to settlement was 32 days at a temperature of approximately 13°C; at temperatures between 8.5° and 10.0°C, settlement was not observed until approximately 55 days after fertilization. Larval growth rates were significantly faster at temperatures between 11.0° and 14.5°C than at temperatures between 8.5° and 10.0°C. Morphometry of the larval shell and morphology of the larval hinge apparatus were independent of larval growth rates and experimental culture conditions.

The smallest shelled veliger observed had length and height dimensions of 95 µm and 75 µm, respectively. Prodissoconch I lengths ranged from 98 µm to 118 µm (n=50). As shell lengths reached 150 to 165 µm, the hinge-line was obscured by the appearance of a low, rounded umbo. The smallest metamorphosing larva observed in any of the cultures had a shell length of 240 µm. Prodissoconch II lengths, as determined from measurements made on 100 early post-larval specimens, ranged from 232 µm to 289 µm. Shell lengths of juvenile specimens, reared under laboratory conditions and in outdoor flow-through tanks, ranged from 1.0 mm to 6.5 mm approximately 7 1/2 months after metamorphosis.

Optical and scanning electron micrograph sequences of larval and early post-larval stages of Arctica are presented in a format designed to provide an adequate basis for comparison with corresponding

stages of other bivalves. It is suggested that use of a similar comprehensive format for presentation of life history data for other bivalve species should provide a means of eliminating the vast majority of practical barriers to the identification of early stages of bivalve molluscs isolated from both plankton and benthic samples.

Supported by: NOAA Sea Grants NA81AA-D-00065 and NA80AA-D-00077; NSF Grant EAR78-15536; and the New Jersey Agricultural Experiment Station.

ESTUARINE / RIVER ECOSYSTEMS

DECOMPOSITION OF PAPER BIRCH AND RED ALDER LEAF LITTER IN A SEAWATER ENVIRONMENT

Brian J. Binder and Robert J. Naiman

Decomposition dynamics of paper birch (Betula papyrifera) and red alder (Alnus rubra) leaves were studied in a seawater environment. Trends observed in the nitrogen, carbon, lignin, cellulose and acid detergent cell wall (ADCW) fraction of the litter over time were similar to those reported for freshwater systems, but decomposition rates in this study were much slower than expected. Even after 140 days (1090 degree days), approximately 70 percent of the original material remained. Although the two species differ significantly in presumed substrate quality, decay rate coefficients (k) were virtually identical ($k=0.0013 \cdot d^{-1}$ for birch leaves; $0.0012 \cdot d^{-1}$ for alder). Correlations previously reported between k and percent nitrogen, C:N ratio, percent lignin, and lignin: nitrogen ratio for terrestrial and freshwater systems failed to predict both the slow rates of decomposition and the striking similarity between species. The absence of significant fungal colonization is postulated to have resulted in the slow decomposition rates.

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WOOD DECOMPOSITION DYNAMICS: INFLUENCE OF SUBSTRATE QUALITY AND STREAM SIZE

Jerry M. Melillo, Robert J. Naiman
and John D. Aber

Woody materials decayed more rapidly in small streams than in large rivers. Rate

constants (k) for annual weight loss were highest ($k = 1.37$) for alder woodchips in a first order stream and lowest ($k = 0.05$) for black spruce wood chips in a ninth order stream. For a variety of materials decomposing in a single stream, the rate constants had a negative inverse curvilinear correlation with the ratio of initial lignin concentration to initial nitrogen concentration.

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THE ANNUAL PATTERN AND SPATIAL DISTRIBUTION OF AQUATIC METABOLISM IN A LARGE BOREAL FOREST WATERSHED

Robert J. Naiman

The level and diversity of metabolism in lotic ecosystems are largely functions of channel geomorphology and hydrology, making site-specific studies difficult to extrapolate to other parts of the watershed. This paper describes the pattern and distribution of aquatic metabolism for a large undisturbed boreal forest watershed in eastern Quebec, Canada. Metabolism by periphyton, mosses, macrophytes, fine particulate organic matter (FPOM: $0.5 \mu\text{m}$ – 1mm), and coarse particulate organic matter (CPOM: $>1\text{mm}$) was examined during the ice-free period (April to November) of 1979 and 1980 in First Choice Creek (1st order; watershed area: 0.25 km^2), Beaver Creek (2nd order; 1.83 km^2), Muskrat River (5th order; 204 km^2), Matamek River (6th order; 671 km^2), and the Moisie River (9th order; $19,871 \text{ km}^2$). As watershed area increases, the level of primary production and the diversity of autotrophic groups are augmented with the development of mosses and macrophyte communities. Total metabolism increases downstream, ranging from $<1 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{d}^{-1}$ in First Choice Creek to nearly $5 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{d}^{-1}$ during summer in the Moisie River. Autotrophic metabolism with few exceptions is not significantly correlated with light or chlorophyll, but annual production is highly correlated with stream order ($r^2 > 0.76$ in most cases). These data are interfaced with a geomorphological analysis of the watershed to discern the spatial distribution of aquatic metabolism and to estimate total aquatic metabolism in the Moisie River drainage network. Mosses, occurring only in streams >4 th order, are shown to be the most productive autotrophic component in the watershed ($3.9 \times 10^{10} \text{ gO}_2 \cdot \text{yr}^{-1}$); by comparison periphyton produce only an estimated $2.1 \times 10^{10} \text{ gO}_2 \cdot \text{yr}^{-1}$. FPOM is the most active detrital component ($6.6 \times 10^{10} \text{ gO}_2 \cdot \text{yr}^{-1}$). Geomorphic analyses

show that streams >4 th order comprise only 1.2 percent of the total number, 12.7 percent of the total length, but 76.8 percent of the lotic surface area, and are responsible for 86.3 percent of the gross production by the entire lotic drainage network. The surface area of lakes is approximately six times that of streams but their contribution (phytoplankton) to the total aquatic ecosystem metabolism is only comparable to that of lotic periphyton. Results demonstrate that it is possible to extend the River Continuum Concept to the watershed level by interfacing biological measurements with geomorphological analyses of the drainage network, thus allowing a detailed description of spatial and temporal patterns for metabolic components and total ecosystem metabolism to be constructed.

Supported by: Matamek Research Program.

FISHES, SHARKS AND RAYS

A BRAIN HEATER IN THE SWORDFISH

Francis G. Carey

The brain and eye of swordfish are warm. Associated with one of the eye muscles is a tissue which heats the brain. This brain heater is rich in mitochondria and cytochrome c and is supplied with blood through a vascular heat exchanger. It protects the central nervous system from rapid cooling during daily vertical excursions which may take the swordfish through a wide temperature range.

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HEAT AND OXYGEN EXCHANGE IN THE RETE MIRABILE OF THE BLUEFIN TUNA, Thunnus thynnus

Francis G. Carey and Quentin H. Gibson

Thunnus thynnus maintains a muscle temperature up to 15°C above its surroundings with a heat exchanger, the rete mirabile. Allowing for surface and mechanical (Joule) heat losses, the rete must transfer 99 percent of the metabolic heat from the venous to the arterial blood. With this high efficiency of heat transfer it is to be expected that some oxygen will also be exchanged, and with a normal hemoglobin this transfer of oxygen from arterial to venous blood in the rete would increase the required cardiac output

by about 20 percent. Tuna hemoglobin shows a temperature dependence (rising affinity with rising temperature) in the opposite direction to that commonly seen. This reversed temperature dependence reduces loss of oxygen two to three fold. The molecular mechanism entails an enhanced temperature dependence of the allosteric parameter L which outweighs normal temperature dependence of the intrinsic heme affinities. The effect is confined to the physiological range of pH and oxygen concentration. Whole blood also shows temperature invariance.

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THE THERMAL ECOLOGY OF THE WHITE SHARK Carcharodon carcharias

Francis G. Carey, John W. Kanwisher,
Oliver Brazier, Geir Gabrielson,
John G. Casey and Harold L. Pratt, Jr.

A large (4.6 m) white shark was followed for 3.5 days while its depth, water temperature and muscle temperature were recorded by acoustic telemetry. During this time the shark moved 190 km from an area south of Montauk Point, New York to Hudson Canyon. It made a number of brief excursions to the surface and to the bottom, but usually swam in the thermocline. Muscle temperature of the shark was as much as 5°C warmer than the water, confirming that a system of large retia mirabilia in the circulatory system function as heat exchangers. The shark did not thermoregulate and muscle temperature changed slowly as water temperature changed. The warming of the muscle as the shark swam into warmer water allowed us to estimate its rate of metabolism. The rate obtained is low and despite being warm, it appears that the shark can maintain itself for more than a month on a single large meal. The implications of this for its feeding habits are discussed.

In press: Copeia.

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COLLAPSE OF STABILITY REGIONS AND OF FISH STOCKS IN A DEVELOPING FISHERY

Geoffrey T. Evans

In developing a fishery on a stock whose surplus production is governed by a logistic or similar growth law, a policy of steadily increasing the fishing quota and

watching the stock carefully is likely to lead to overfishing: at the time of greatest danger, there are no signs to watch for. Increasing nominal effort for a schooling fish stock has similar problems. A policy of steadily increasing fishing mortality, although more difficult to implement, runs less risk of overfishing.

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THE FUNCTION OF HIGH HEMOGLOBIN IN LARGE FISH

Quentin H. Gibson and Francis G. Carey

Over the years, a considerable body of evidence has accumulated which shows that fish hemoglobins not only differ from mammalian hemoglobin, but also differ greatly from one another (1,2,3). A large amount of work is involved in characterizing the function of a hemoglobin in detail, so relatively few have been studied fully. It seems, however, that there may be three general classes of fish hemoglobins. The first is the Root effect hemoglobins, in which one chain has a very low affinity for ligand in the T-state, and which show a marked change in affinity with pH (4). Second, and coexistent in the same fish with the Root effect hemoglobins, are the pH invariant and effector independent hemoglobins, studied first by Hashimoto and Matsuura (5) and since examined in great detail here in Rome as trout I. The third group includes the shark hemoglobins which are cooperative, have chains which are alike in the T-state, and respond only moderately to pH change and to effectors (6,7,8). In looking for an explanation of this functional diversity it is natural to think first of the transport function of hemoglobin in fishes. There is, however, a good deal of evidence to suggest that many fishes can manage quite well without it. Rather more than 50 years ago, Nicloux (9) converted the hemoglobin of several species of fishes to COHb, and came up with the surprising result that their behavior was not visibly affected. These observations were, of course, made under aquarium conditions, and the fish might be handicapped in nature. There are, however, several species of fishes with blood free from hemoglobin which occur in nature (10,11). This situation contrasts so strongly with experience in mammals as to justify more detailed investigation.

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A NOTE ON ATLANTIC SALMON FRY INTRODUCED INTO A NATIVE BROOK TROUT POPULATION

Frederick G. Whoriskey, Jr.
and Robert J. Naiman

In 1979, approximately 5,000 Atlantic salmon (*Salmo salar*) fry were released in an area of the Matamek River, Quebec, devoid of salmon but having a population of native brook trout (*Salvelinus fontinalis*). By 1980 salmon parr occupied primarily two areas within the study site: a shallow riffle previously devoid of trout and a deeper area at the riffle base where they were outnumbered by trout. In 1980 trout of age 1+ were significantly smaller than 1+ trout captured in 1979, but were larger than 1+ trout captured in 1971 and 1974 previous to any salmon introductions. No significant size difference was noted between the two years for older trout. Salmon parr growth was excellent with a mean length of 12.1 cm attained by the end of the second summer. Competition for food may partially explain the 1+ trout size differences between years. Seventy-one percent of the male salmon parr sampled were mature. Successful establishment of salmon appeared to have little effect on the trout population.

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EFFECTS OF COMMERCIAL FISHING ON ADULT ATLANTIC SALMON (*Salmo salar*) IN A QUEBEC RIVER

Frederick G. Whoriskey Jr.
and Robert J. Naiman

Despite an absence of freshwater exploitation, the adult salmon run in the Matamek River, Quebec, declined during 1975-1980 to <23 percent of the level thought to occur there prior to 1967. Returns in 1979 and 1980 of adults tagged as smolts were 1.0 percent and 0.9 percent, respectively. Numbers of emigrating smolts and their corresponding adult returns are not significantly correlated, although we observed a trend towards more salmon (2 sea-year fish) returning with larger numbers of migrating smolts. Since 1967 there is noted a decrease in the age at which returning adults smolted and females appear to now constitute a larger percentage of returning grilse and salmon. These, and other changes in life history characteristics, appear to be caused solely by commercial exploitation.

Supported by: Matamek Research Station.

MARINE MAMMALS

RIGHT WHALE, *Eubalaena glacialis*, SIGHTINGS IN CAPE COD WATERS

William E. Schevill, Karen E. Moore
and William A. Watkins

Sightings of right whales, *Eubalaena glacialis*, in Massachusetts waters have been recorded by workers at Woods Hole Oceanographic Institution since 1955. These observations do not represent a census because emphasis was placed on studying the whales' underwater sounds and other activities. The number of yearly sightings varied from 2 to 165. Observations were made from aircraft, boats, and occasionally from shore.

WHOI Technical Report 81-50.

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CORRELATION OF ACTIVITIES AND UNDERWATER SOUNDS OF FINBACK WHALES (*Balaenoptera physalus*)

William A. Watkins

Routine activities observed in finback whales (*Balaenoptera physalus*) were correlated with their underwater sounds. The 23 years of acoustic and behavioral observations were from a variety of geographical areas, but were more frequent in waters of the northwestern Atlantic around Cape Cod, Massachusetts, USA. Shipboard and aerial observations using arrays of hydrophones with low-frequency capability and radio tracking of tagged whales provided confirmation of both acoustics and behaviors. Routine activities were described including blowing, short dives (apparently a search behavior), long dives (often feeding), near surface slow swimming (resting), rapid travel, and surface feeding. Underwater sounds included higher frequency sounds, 20-Hz pulses (both single pulses and patterned sequences), ragged broad-band low frequency pulses and low-frequency rumbles, as well as non-vocal sharp impulsive sounds. Occurrence of the sounds, typical levels, responses, seasonality, and relationship to behavior suggested that the sounds were used in specific ways: the higher frequency sounds appeared to be for communication with nearby finbacks, the 20-Hz single pulses seemed to be used for both local and longer distance communication, the patterned seasonal 20-Hz pulses appeared to be courtship displays, the low-frequency rumble seemed to have

surprise or agonistic significance, and the non-vocal impulsive sounds apparently were adventitious and related to surface feeding. Other sounds and behaviors were not as well defined or repeated enough for such analysis. Mechanisms of sound production, the effect of the environment on the low frequency sounds, the propagation of these sounds, and the relationship of the sounds from similar whale species is discussed.

In press: Scientific Reports of the Whales Research Institute, Tokyo.

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RADIO TAGGING OF FINBACK WHALES - ICELAND, JUNE-JULY 1980

William A. Watkins

In June and July, 1980, finback whales (*Balaenoptera physalus*) were radio tagged in the waters west of Iceland. One double-tagged finback was tracked continuously with shipboard receiving gear for 9 1/2 days for over 2,095 km, during which it swam with from one to seven companion finbacks to within 130 km of Greenland. The tagging and tracking systems worked well. New behavioral information about finbacks was gathered, and new questions were raised concerning this population's movements and distribution. Whale integument is discussed and the potential retention of transcutaneous whale tags is analyzed.

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RADIO TRACKING OF A FINBACK WHALE (*Balaenoptera physalus*) FROM ICELANDIC TO GREENLAND WATERS

William A. Watkins, Karen E. Moore, Johann Sigurjonsson, Douglas Wartzok and Giuseppe N. di Sciara

A finback whale, *Balaenoptera physalus*, with two implanted radio tags was tracked continuously for 2,000 km over 9 1/2 days, from the whaling area 135 km southwest of Iceland to within 130 km of Angmagssalik, Greenland. After tagging, the whale fed on krill off Iceland for a day and then with up to seven companion finbacks swam for five days to the Greenland area where it began feeding apparently on small fish. The whales appeared to be undisturbed by the radio tags.

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MARINE POLLUTION

PHYSIOLOGICAL EFFECTS OF PETROLEUM HYDROCARBONS ON MARINE LARVAL CRUSTACEANS: HYDROCARBON ACCUMULATION AND INTERFERENCE WITH LIPID METABOLISM

Judith M. Capuzzo

The energetics of larval development and metamorphosis of marine crustaceans are disrupted with exposure to petroleum hydrocarbons. The importance of lipids as energy reserves for the larval stages of marine crustaceans and the bioaccumulation of lipid-soluble hydrocarbon components suggest that disruption in energetics may be due to an interference with lipid storage and synthesis. In continuous flow bioassays, the physiological effects of naturally dispersed and chemically dispersed South Louisiana crude oil-seawater mixtures and ingestion of an oil-contaminated food source on larvae of the American lobster *Homarus americanus* have been investigated. Disruption in energetics of larval stages was observed and correlated with a shift in the normal pattern of lipid utilization. No differences were apparent in the toxic effects of naturally dispersed and chemically dispersed crude oil seawater mixtures to larval lobsters, indicating that the increased availability of microdroplets of oil in the chemically dispersed suspensions did not influence toxic effects. Larval lobsters fed an oil-contaminated food source showed earlier signs of stress than larvae exposed to crude oil-seawater mixtures; the later larval stages, however, also showed some restoration of normal energetic patterns during the 96 h exposure. Hydrocarbon turnover appeared to be rapid and little accumulation of petroleum hydrocarbons was observed in larval lobsters under the various exposure conditions. The relationship of developmental and energetic abnormalities of larval crustaceans exposed to petroleum hydrocarbons is discussed.

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PREDICTING POLLUTION EFFECTS IN THE MARINE ENVIRONMENT

Judith M. Capuzzo

Predicting the overall impact of pollutant discharges in the marine environment requires an understanding of the responses of both individual organisms and whole populations, as well as the adaptive or destructive nature of such responses. The impact of pollutants on marine life has been traditionally assessed using standard laboratory bioassay techniques. In these assays, the major criterion used to determine an organism's response to a toxicant stress is the measurement of an LC₅₀ value; i.e., the concentration of a pollutant that results in 50 percent mortality of the test organisms during a designated exposure period. Although these data on lethal exposure are useful in detecting the sensitivity of an organism to a particular pollutant, in comparing the relative toxicities of various pollutants, and in establishing potential effluent guidelines, important physiological, behavioral and ecological changes that may occur with sublethal exposure are not measured in the standard bioassay. In addition to bioassays, responses of pollutants can be determined at five levels of biological organization: biochemical and cellular responses, organismal responses, including the integration of physiological and behavioral changes; community responses under simulated controlled conditions; alterations in population dynamics; and alterations in community dynamics and structure. All responses are not disruptive in nature and do not necessarily result in the degeneration of the next level of organization. Only when the compensatory or adaptive mechanisms at one level begin to fail, do deleterious effects become apparent at the next level. For predictive purposes, one must be aware of the early warning signs of stress at each level before compensatory mechanisms are surpassed. From the biochemical level to the community level, the degree of system complexity, the number of compensatory mechanisms available, and the lag time to measure a response increase exponentially, therefore increasing the predictive difficulties at each level. Continued research is needed at each level of biological organization in order to insure a detailed, integrative understanding of the effects of pollutants on the marine environment.

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CONCENTRATIONS OF ELEMENTS IN A MARINE FOOD CHAIN CULTURED IN SEWAGE WASTEWATER

A. Keith Furr, Thomas F. Parkinson,
John Ryther, Carl A. Bache,
Walter H. Gutenmann, Irene S. Pakkala
and Donald J. Lisk

Considering the earth's given land area and ever increasing population, much research is presently underway to utilize and cultivate fresh water and marine species as an additional source of protein (Bardach et al., 1972). One of the main obstacles to this endeavor is water pollution, with the probability of absorption, concentration and biological magnification of toxic constituents. Of special significance in this regard are current attempts to utilize domestic wastewater as a basic source of nutrients for growing aquatic organisms (Allen and Carpenter, 1974; D'Itri, 1975; Ryther et al., 1972). The effluent from conventional secondary sewage treatment is particularly appropriate for this purpose since it contains in dissolved form most of the nutrients (N, P, etc.) originally present in untreated wastewater, while most of the toxic trace contaminants, both organic and inorganic, are usually adsorbed or otherwise bound to the particulate fraction and carried down in the sludge during the secondary sewage treatment process (Chen et al., 1974). This is not true of all trace contaminants, however, as some are highly soluble and remain in the effluent fraction at significant concentrations. Furthermore, even those that may be present at very low, even undetectable, levels in the sewage effluent may subsequently become concentrated in the cultivated organisms and their concentrations further amplified by passage up the food chain (Woodwell et al., 1967).

It is essential to learn which elements and organic constituents in treated sewage effluent are absorbed by aquatic species and whether the magnitude of absorption may constitute a hazard to consumers. In the work reported, an aquatic food chain including seaweed, clams, oysters, lobsters and flounder has been cultured in secondary sewage effluent from the Wareham, Massachusetts, treatment plant. The aquatic organisms were then analyzed for 44 elements by neutron activation, flameless atomic absorption, anodic stripping voltammetry and other methods. Element concentrations in the sewage sludge (collected from the final clarification stage) was also analyzed and is reported to demonstrate the probable origin of the elements found in the cultured organisms.

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

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

The macrofauna and meiofauna of three oiled and three control experimental ecosystems at the Marine Ecosystems Research Laboratory (MERL) were followed for 25 weeks of semi-continuous additions of an oil-water dispersion of No. 2 fuel oil. Water column hydrocarbon levels were maintained at about 190 ppb, and after 20 weeks 109 µg/g dry weight fuel oil hydrocarbons were recorded in the top 2 cm of sediment.

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

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QUANTITATIVE STUDIES OF MACROFAUNA IN THREE BENTHIC COMMUNITIES IN EXPERIMENTAL ECOSYSTEMS

J. Frederick Grassle, Judith P. Grassle, L. Susan Brown-Leger, Nancy J. Copley and Rosemarie F. Petrecca

Results from five years of seasonal samples at a Middle Bay station near Jamestown indicate sharp reductions in individuals and species in late summer for three of the five years. These declines are followed by increases in the relatively opportunistic Mulinia lateralis and Mediomastus ambiseta.

Populations of Nucula annulata increase along a gradient from a Providence River station to an offshore station at the mouth of Narragansett Bay. Mulinia lateralis follows a gradient in the opposite direction and Mediomastus ambiseta and Yoldia limatula peak at the Middle Bay station.

When the three communities from the Bay were brought into groups of three MERL tanks the numbers declined and remained low throughout the 20-month experiment. A combination of predation by Crangon septemspinosus, water and sediment quality, and reduced larval recruitment account for the low numbers. Further experiments are needed to separate the relative importance of these factors.

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THE EFFECTS OF DRILLING FLUIDS ON MARINE CRUSTACEANS: A REVIEW OF BIOASSAY TECHNIQUES AND PHYSIOLOGICAL AND BEHAVIORAL RESPONSES

Jennifer G. Smith Derby and Judith M. Capuzzo

Drilling fluids (drilling muds) are the major effluent from offshore drilling operations. Because marine crustaceans are ecologically and commercially important in offshore habitats where drilling occurs or has been proposed, they have been used extensively as test organisms in bioassays evaluating the effects of drilling fluid discharges. This discussion compares bioassay techniques with emphasis given to sublethal measurements of drilling fluid toxicity.

Acute and chronic bioassays of used, whole drilling fluids have demonstrated a wide variation in the toxicities of different drilling fluids. Drilling fluids from a single well differed in toxicity depending on the well depth and drilling conditions when collected. One example of such variability in individual muds is a range of 161 ppm to greater than 25,000 ppm 96 h LC₅₀ values reported for Mysidopsis (mysid shrimp).

Sublethal effects of used, whole drilling fluids have been examined. Studies on various life stages of the lobster, Homarus americanus, reported alterations in growth rates, respiration rates, biochemical composition, and chemosensory and behavioral responses with sublethal drilling fluid exposures.

Water-soluble fractions and individual components of drilling fluids have been assayed for effects on various warm- and cold-water species. Findings demonstrate that larval, juvenile and early postecdysial adult crustaceans are particularly sensitive stages. Several studies have indicated that much of the

toxicity of drilling fluids resides in the water-soluble fraction. However, there is also histopathological evidence of harmful effects caused by the major particulate component, barite. Biocides, especially the chlorophenols, were some of the most toxic components tested, with inhibitory developmental effects at concentrations as low as 0.565 ppm in Palaemonetes pugio.

The application of bioassay and sublethal monitoring in establishing drilling permit discharges in offshore areas is discussed.

Supported by: EPA under Cooperative Agreement CR807447 with the Gulf Breeze Environmental Research Laboratory.

LABORATORY AND FIELD APPROACHES TO ENVIRONMENTAL EFFECTS MONITORING WITH EMPHASIS ON SOME MICROBIAL - HEAVY METAL RELATIONS

Ralph F. Vaccaro

Over the past 30 years an increasingly rigid rationale has evolved concerning what constitutes acceptable environmental impacts from the release of society's wastes. This trend, particularly pronounced with regard to the oceans, has in turn generated an unfulfilled demand for more discerning effects monitoring to disclose prevailing levels of environmental stress. The perplexing shortfall regarding environmental effects monitoring is somewhat analogous to that of an employee paid to rid a certain section of beach of cans, bottles and other debris only to be abruptly confronted with the additional task of counting all brown sand particles.

Current environmental concern places significant emphasis on community structure and population interaction; a viewpoint eminently consistent with the classical definition of a biological ecosystem which stresses both population and substrate interactions. Proponents of the ecosystem approach to environmental quality standards hold that man's critical interests are best served by a conscientious regard for earth's renewable resources and that any impact on community function is inadmissible. The consequential need to examine entire ecosystems, as well as individual organisms, is a prime reason for today's unprecedented need for more responsive environmental monitoring.

In press: Proceedings NATO-A10L Workshop on Trace Element Speciation in Surface Waters and Its Ecological Implications, Nervi, Italy, November 1981.

Supported by: WHOI.

THE OCEANS AND U.S. SEWAGE SLUDGE DISPOSAL STRATEGY

Ralph F. Vaccaro, Judith M. Capuzzo and Nancy H. Marcus

The practice of dumping barged sewage sludge at disposal sites along the northeast coast of the United States is scheduled to terminate by the end of this year. By law, only nonmarine solutions to sludge disposal will be acceptable at that time. This legislation, however, is now being questioned because of doubts concerning the costly alternative disposal strategies being advanced by the regulatory agencies. Support for a more balanced approach to sludge disposal, utilizing the combined potentials of land, sea and atmosphere, is slowly gaining favor. One of the obstacles to a balanced solution is the lack of information available on the effectiveness of offshore as opposed to nearshore receiving areas for sludge disposal. Thus far, barged sewage sludge has been dumped in relatively shallow coastal waters of the continental shelf. Recent observations on deep-water waste disposal encourage a look toward a broader oceanic role in future management.

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

ASSIMILATORY SULFUR METABOLISM IN MARINE MICROORGANISMS: CONSIDERATIONS FOR THE APPLICATION OF SULFATE INCORPORATION INTO PROTEIN AS A MEASUREMENT OF NATURAL POPULATION PROTEIN SYNTHESIS

Russell L. Cuhel, Craig D. Taylor and Holger W. Jannasch

The sulfur content of residue protein for pure cultures of Nitrosococcus oceanus, Desulfovibrio salexigens, 4 mixed populations of fermentative bacteria, 22 samples from mixed natural population enrichments, and 11 nutritionally and morphologically distinct isolates from enrichments of Sargasso Sea water compared favorably with the sulfur content of residue protein from extensive work with Pseudomonas halodurans and Alteromonas luteo-violaceus. The average 1.09 ± 0.14 weight percent S in protein for 13 pure cultures agrees with the 1.1 percent

calculated from average protein composition (15). An operational value encompassing all mixed population and pure culture measurements has a coefficient of variation of only 15.1 percent ($n=41$).

Short-term ^{35}S -sulfate incorporation kinetics by *P. halodurans* and *A. luteo-violaceus* demonstrated a rapid appearance of ^{35}S in the residue protein fraction which was well modeled by a simple exponential uptake equation. This indicates that little error in protein synthesis determination results from isotope dilution by endogenous pools of sulfur-containing compounds.

The effects of organic sulfur compounds (cystine, methionine, and glutathione) at moderate concentrations ($1-10\ \mu\text{M}$) on sulfate incorporation into residue protein and ^{35}S distribution in major biochemical fractions of *P. halodurans* were investigated. Methionine effectively competed with sulfate for protein synthesis at high concentrations ($10\ \mu\text{M}$), but had much less influence at $1\ \mu\text{M}$. Cystine competed less effectively with sulfate, and glutathione did not detectably reduce sulfate-S incorporation into protein.

^{35}S -sulfate incorporation into residue protein was compared with ^{14}C -glucose assimilation in a eutrophic brackish water environment. Both tracers yielded similar results for the first 8 hours of incubation, by which time most of the glucose had been metabolized and assimilation of ^{35}S and ^{14}C had reached a plateau. A secondary growth phase was observed with ^{35}S , resulting in a doubling of incorporated ^{35}S at 12 hours. Total carbon assimilation did not increase; however, movement of ^{14}C from low molecular weight materials into residue protein indicated additional protein synthesis.

^{35}S -sulfate incorporation into residue protein by marine bacteria can be used to quantitatively measure bacterial protein synthesis in unenriched mixed populations of marine bacteria.

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ASSIMILATORY SULFUR METABOLISM IN MARINE MICROORGANISMS: SULFUR METABOLISM, PROTEIN SYNTHESIS, AND GROWTH OF *Alteromonas luteo-violaceus* AND *Pseudomonas halodurans* DURING PERTURBED BATCH GROWTH

Russell L. Cuhel, Craig D. Taylor and Holger W. Jannasch

The antibiotic protein synthesis inhibitor chloramphenicol specifically blocked the incorporation of ^{35}S -sulfate into the residue protein of two marine bacteria, *Pseudomonas halodurans* and *Alteromonas luteo-violaceus*. Parallel inhibition of total protein synthesis occurred, but incorporation of ^{35}S into low molecular weight (L.M.W.) organic compounds continued. *A. luteo-violaceus* rapidly autolyzed, with similar reduction in cell counts, total culture protein and cellular sulfur, whereas *P. halodurans* remained viable.

Treatment with chloramphenicol, growth during nitrogen and carbon limitation, and the carbon and energy source used for growth did not alter the sulfur content of *P. halodurans* protein; the mean value was in good agreement with model protein composition under a wide variety of environmentally relevant growth conditions.

The variability of cellular composition of *P. halodurans* and *A. luteo-violaceus* is discussed with respect to the measurement of bacterial growth in natural environments. Total carbon and nitrogen per cell varied greatly (C.V.~100 percent) depending on growth conditions. Variation in total sulfur and protein per cell was much less (C.V.<50 percent), but the least variation was found for sulfate incorporation into residue protein (C.V.~15 percent). Thus sulfate incorporation into residue protein provides the best estimate of marine bacterial growth.

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ASSIMILATORY SULFUR METABOLISM IN MARINE MICROORGANISMS: SULFUR METABOLISM, GROWTH, AND PROTEIN SYNTHESIS OF *Pseudomonas halodurans* AND *Alteromonas luteo-violaceus* DURING SULFATE LIMITATION

Russell L. Cuhel, Craig D. Taylor and Holger W. Jannasch

Sulfate concentration in the growth medium exerted a strong influence on the

sulfur content of protein in two marine bacteria, Pseudomonas halodurans and Alteromonas luteo-violaceus, but the distribution of sulfur in major biochemical fractions was independent of sulfate concentration. Ninety percent of the total cellular sulfur was contained in low molecular weight (L.M.W.) organic compounds and protein; inorganic sulfate was not an important component. The sulfur content of isolated protein and total cellular sulfur increased in proportion to the external sulfate concentration for both bacteria, reaching a maximum at about 100-250 μ M. Only the growth rate of P. halodurans was dependent on the sulfate concentration.

Sulfur starvation of cells labeled to equilibrium with ^{35}S -sulfate resulted in a rapid decrease in L.M.W. organic S with a concomitant increase in alcohol soluble (P. halodurans) or residue protein (A. luteo-violaceus). Although cell division was prevented, total protein increased in both bacteria, resulting in synthesis of sulfur-deficient protein. This effect was most pronounced in P. halodurans.

Addition of ^{35}S -sulfate to sulfur-starved A. luteo-violaceus further demonstrated that sulfur metabolism is restricted primarily to the synthesis and utilization of sulfur-containing protein precursors. The L.M.W. organic S pool is replenished rapidly, and the pool size per cell reaches twice the normal value before cell division resumes. Incorporation into protein is very rapid.

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ASSIMILATORY SULFUR METABOLISM IN MARINE MICROORGANISMS: SULFUR METABOLISM, PROTEIN SYNTHESIS, AND GROWTH OF Pseudomonas halodurans AND Alteromonas luteo-violaceus DURING UNPERTURBED BATCH GROWTH

Russell L. Cuhel, Craig D. Taylor and Holger W. Jannasch

Analysis of the distribution of ^{35}S -sulfate and ^{14}C -glutamate in major biochemical components of two marine bacteria, Pseudomonas halodurans and Alteromonas luteo-violaceus, was compared with cell density and total cellular protein during exponential growth in batch culture. For both organisms, the sulfur distribution was restricted principally to the low molecular weight (L.M.W.) organic

and protein fractions, which together accounted for over 90 percent of the total sulfur. Carbon was more widely distributed, with these two fractions containing only 70 percent of the total label.

Growth rate constants calculated from increases in cell numbers, protein, and ^{35}S and ^{14}C in the various fractions indicated nearly balanced growth in A. luteo-violaceus, with constants derived from all biosynthetic parameters agreeing within 5 percent during the exponential phase. In contrast, protein synthesis and ^{35}S incorporation into residue protein constants were 30 percent higher than constants derived from cell counts and incorporation of ^{14}C in P. halodurans. Therefore the cellular protein content P. halodurans varied over a two-fold range, with maximum protein per cell in the late exponential phase. A distinct reduction in the rate constants for total protein and ^{35}S incorporation into residue protein foreshadowed entry into the stationary phase more than one generation before other parameters.

Incorporation of ^{35}S -sulfate into residue protein paralleled protein synthesis in both bacteria. The weight percent S in protein agreed well with the composition of an "average protein" derived from the literature. Sulfur incorporation into protein may be a useful measurement of marine bacterial protein synthesis.

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BACTERIAL GROWTH AND PROTEIN SYNTHESIS IN THE NORTHWESTERN ATLANTIC OCEAN

Russell L. Cuhel, Holger W. Jannasch, David R. S. Lean and Craig D. Taylor

Assimilation of sulfate, phosphate and ammonia by unenriched natural populations of marine bacteria was investigated along a transect from Woods Hole to the northern Sargasso Sea. Uptake of inorganic nutrients was generally non-linear; in fact, a substantial lag phase was observed for both sulfate and ammonia assimilation at the two most inshore stations. Uptake of acetate, glucose and glutamate was exponential for 16 hours which yielded calculated population doubling times under four hours.

The distribution of incorporated radiolabels into major biochemical

components (e.g., low molecular weight, lipids, RNA, protein) was determined. For the continental slope station, an increase in phosphate incorporation into lipid and RNA coincided with the first detection of sulfate and ammonia assimilation. Incorporation patterns of the organic compounds indicated preferential utilization of individual substrates by specific biosynthetic pathways.

The bacterial population in the Sargasso Sea exhibited the lowest potential biomass production. However, both the time-course of uptake and the distribution of radiolabels in the major biochemical fractions more closely resembled balanced microbial growth than at any of the other stations. Overall, the data indicated an inshore/offshore gradient in potential biomass production; low in the Sargasso Sea, modest over the continental slope, and high in shelf waters. Gross nutrient uptake, when coupled with analysis of the distribution of the tracers in specific subcellular components, provided a means of quantitatively assessing the growth and physiological state of unenriched natural bacterial populations.

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AN ANAEROBIC SPIROCHETE FROM DEEP-SEA HYDROTHERMAL VENTS

C. S. Harwood, Holger W. Jannasch and E. Canale-Parola

An obligately anaerobic spirochete was selectively isolated from samples collected at a deep-sea hydrothermal vent (2,500 m) of the Galapagos Rift ocean floor spreading center. The morphological and physiological characteristics of the spirochete (strain GS-2) resembled those of free-living spirochetes belonging to the genus *Spirochaeta*. However, strain GS-2 had a much slower growth rate and grew to lower yields than previously described species of this genus. The occurrence of obligately anaerobic bacteria at the hydrothermal vents is an indication that water is anoxic in at least some section of the vents. Furthermore, the presence of strain GS-2 in the vicinity of hydrothermal vents shows that these particular deep-sea areas provide a favorable environment for anaerobic marine spirochetes.

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ASPECTS OF MEASURING BACTERIAL ACTIVITIES IN THE DEEP OCEAN

Holger W. Jannasch

A discussion of (i) the significance of biomass determinations and of potential vs. direct measurements of microbial activities in the oligotrophic deep-sea environment, (ii) the effects of decompression prior to uptake measurements, and (iii) the chemo-synthetic eutrophication at hydrothermal deep-sea vents is presented.

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INTERACTIONS BETWEEN THE CARBON AND SULFUR CYCLES IN THE MARINE ENVIRONMENT

Holger W. Jannasch

The bacterial reductions and oxidations of sulfur compounds have an auxiliary function in the transformation of inorganic to organic carbon. Sulfate acts as an additional electron acceptor when free oxygen is consumed and is quantitatively more important in the marine environment than nitrate and bicarbonate. A number of new genera of sulfate-reducing bacteria have been described recently. In the flow of energy, the oxidation of hydrogen sulfide by chemosynthetic bacteria must be considered as secondary production. In the marine environment, obligately chemo-autotrophic, acid-producing sulfur oxidizers are less prevalent than facultatively chemoautotrophic, base-producing (polythionate) sulfur oxidizers. Anaerobic photosynthetic sulfide oxidation occurs in estuaries only. The global amount of chemosynthetic production is minimal as compared to photosynthetic production. Chemosynthesis has been found to sustain rich invertebrate populations clustered around sulfide emitting hydrothermal deep-sea vents.

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MICROBIAL ACTIVITIES IN UNDECOMPRESSED AND DECOMPRESSED DEEP SEA WATER SAMPLES

Holger W. Jannasch and Carl O. Wirsen

Microbial transformations of ^{14}C -labeled substrates (Na-glutamate, Casamino Acids, glucose, and Na-acetate) were measured in undecompressed seawater samples collected from depths of 1,800 to 6,000 m during 14 to 21 days' incubation periods at *in situ* temperature (3°C). Each substrate was tested at two concentrations

(approximately 0.5 and 5.0 $\mu\text{g/ml}$), two *in situ* pressures, and the data compared to 1 atm controls. The rates of ^{14}C -incorporation and $^{14}\text{CO}_2$ -production as well as the amounts of total substrate utilization were generally lower at pressure than in the decompressed controls but were significantly different for each of the four substrates used. The utilization of acetate was the least affected by pressure; rates were similar to those measured at 1 atm in two out of four experiments. In contrast, transformation rates of the amino acids at pressure averaged only 38 percent of those in the controls. A single but reproducible "barophilic" response was observed with glucose as a substrate in samples collected from a depth of 4,500 m at a specific area in the northwest Atlantic. Except for this latter set of experiments, the transformation of all substrates showed an increased lag period at pressure as compared to the 1 atm controls.

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MICROBIOLOGY OF THE DEEP SEA

Holger W. Jannasch and Carl O. Wirsen

An overview of recent advances in deep sea microbiology is presented.

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PRODUCTION OF NO AND N_2O BY SOIL NITRIFYING BACTERIA: A SOURCE OF ATMOSPHERIC NITROGEN OXIDES

Fred Lipschultz, Oliver C. Zafiriou, Stephen C. Wofsy, M. B. McElroy, Frederica W. Valois and Stanley W. Watson

The composition of the atmosphere is influenced both directly and indirectly by biological activity. Evidence is presented here to suggest that nitrification in soil is a potentially significant source of both NO and N_2O . Between 0.3 and 10 percent of the ammonium oxidized by cultures of the soil bacterium *Nitrosomonas europaea* is converted to these gases. The global source for NO associated with nitrification could be as large as 15×10^6 tonnes N yr^{-1} , with a source for N_2O of $5\text{--}10 \times 10^6$ tonnes N yr^{-1} . Nitric oxide has a key role in tropospheric chemistry,

participating in a complex set of reactions regulating OH and O_3 (refs 1,2). Nitrous oxide is a dominant source of stratospheric NO (refs 3-5) and has a significant influence on climate.

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CHEMOLITHOTROPHIC SULFUR-OXIDIZING BACTERIA FROM THE GALAPAGOS RIFT HYDROTHERMAL VENTS

Edward G. Ruby, Carl O. Wirsen and Holger W. Jannasch

Three distinct physiological types of sulfur-oxidizing bacteria were enriched and isolated from samples collected at several deep-sea hydrothermal vents (2,550 m) of the Galapagos Rift ocean floor spreading center. Twelve strains of the obligately chemolithotrophic genus *Thiomicrospira* were obtained from venting water and from microbial mats covering surfaces in the immediate vicinity of the vents. From these and other sources two types of obligately chemoheterotrophic sulfur-oxidizers were repeatedly isolated that oxidized thiosulfate either to sulfate (acid-producing; nine strains), or to polythionates (base-producing; 74 strains). The former were thiobacilli-like, exhibiting a thiosulfate-stimulated increase in growth and CO_2 incorporation, while the latter were similar to previously encountered pseudomonad-like heterotrophs. The abundance of chemolithotrophic sulfur-oxidizing bacteria, in conjunction with the presence of reduced sulfur compounds in the hydrothermal water, supports the hypothesis that chemosynthesis provides a substantial primary food source for the rich populations of invertebrates found in the immediate vicinity of the vents.

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USE OF MICROBIAL ENRICHMENTS FOR THE STUDY OF THE ANAEROBIC DEGRADATION OF CHOLESTEROL

Craig D. Taylor, Steven O. Smith and Robert B. Gagosian

To demonstrate the potential of model microbial assemblages in studies of the biogeochemistry of complex organic molecules, anaerobic microbial enrichments capable of degrading cholesterol (Cholest-5-en-3 β -ol) have been constructed from marine sediment sources. The bacterial enrichments actively mineralized

the C-4 nucleus of the cholesterol ring system to carbon dioxide when nitrate was present as the terminal electron acceptor. Nitrite was found as an intermediate in the reduction of nitrate, indicating the presence of denitrifying bacteria in the enrichments. When sulfate was supplied as the sole electron acceptor active dissimilation of cholesterol was not observed. In enrichments containing 5 mM nitrate, 95-98 percent of the added cholesterol was recovered as carbon dioxide (2-5 percent), transformation products (20-30 percent), or as the unmodified sterol (70-80 percent). Cholesterol transformation products thus far identified include 5 α - and 5 β -cholestan-3 β -ol, Cholest-4-en-3-one, 5 α -androstan-3, 17-dione, and 4-androsten-3, 17 dione. There is indirect evidence to suggest the presence of multihydroxylated sterols and non-steroid intermediates.

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PHYTOPLANKTON

ENCYSTMENT IN A DYNAMIC ESTUARINE ENVIRONMENT: SELECTIVE DEPOSITION OF DINOFLAGELLATE CYSTS BY A FRONTAL CONVERGENCE

Mary Altalo Tyler, D. Wayne Coats and Donald M. Anderson

The dinoflagellate Gyrodinium uncatenum forms massive summer red tides in the Chesapeake Bay and tributary estuaries. The spatial distribution of these blooms appears delimited in the downstream direction by an estuarine flowfront which appears to serve as a mechanism to concentrate and recirculate the population. Toward the end of the bloom cycle, Gyrodinium sexual stages appear in the water column and show similar patterns of distribution as the vegetative forms in relation to frontal convergence. Late planozygotes - early hypnozygotes appear to be transported downward along the frontal interface, which is the surface expression of the major pycnocline of the estuary. These stages remain associated with the pycnocline and net upstream flowing bottom waters to an area where the pycnocline intersects the bottom. Upstream of this area, motile cells and sexual stages are absent from the water column. Examination of sediments indicates that cysts of Gyrodinium uncatenum are present in highest

concentrations in areas where the pycnocline intersects the bottom. Streamflow-induced variations in the location of the estuarine front in 1979 and in 1980 result in deposition of cysts in different regions, predictable from examination of the location of the convergence. Thus, it is proposed that the convergence zone of the estuarine front and associated pycnocline serves to transfer encysting dinoflagellate forms from surface waters to their ultimate seed bed locations.

In press: *Marine Ecology Progress Series*.

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VERTICAL AND HORIZONTAL DISTRIBUTIONS OF DINOFLAGELLATE CYSTS IN SEDIMENTS

Donald M. Anderson, David G. Aubrey, Mary A. Tyler and D. Wayne Coats

Studies of the distribution of dinoflagellate resting cysts have typically focused on the flocculent layer at the sediment/water interface. Simple coring methods now reveal a wide variety of vertical cyst profiles in different estuarine and nearshore environments, often with significant subsurface concentrations of viable cysts. No general correlation is apparent with sediment type, as both subsurface and surface maxima are found in coarse and fine sediments. The results have important implications with respect to maps of dinoflagellate cyst distribution, to correlations between the observed patterns and hydrographic or sedimentary parameters, and to assessments of the role of this life cycle stage in "seeding" dinoflagellate blooms.

In press: *Limnology and Oceanography*.

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FREE AMMONIA INHIBITION OF ALGAL PHOTOSYNTHESIS IN INTENSIVE CULTURES

Yossef Azov and Joel C. Goldman

The effect of free NH₃ inhibition of short term photosynthesis was investigated in three microalgal species: the freshwater chlorophyte, Scenedesmus obliquus, the marine diatom Phaeodactylum tricornutum and the marine chlorophyte Dunaliella tertiolecta. By performing a series of assays at varying concentrations of added NH₄Cl and culture pH, it was

possible to demonstrate that the inhibitory compound was free NH_3 and that pH played no role in determining the magnitude of inhibition, other than in establishing the degree of dissociation of non-toxic NH_4^+ to toxic NH_3 . When corrections were made for pH, all three species displayed the same sigmoidal response curve to free NH_3 concentration - 1.2 mM NH_3 led to 50 percent reduction in photoassimilation of ^{14}C . Based on literature values, some marine phytoplankton appear to be significantly more sensitive to free NH_3 than the test species which are noted for their excellent growth characteristics. However, the combination of low algal biomass and strong pH buffering commonly found in most marine and many freshwater environments probably limits the possibilities for NH_3 toxicity to low alkalinity freshwaters and intensive algal cultures in which NH_4^+ is the main source of N. Such conditions occur commonly in algal wastewater treatment systems.

In press: Applied and Environmental Microbiology.

Supported by: Rothschild Foundation and Solar Energy Research Institute Subcontract XR-9-91441.

PERSISTENT DIEL RHYTHMS IN CHLOROPHYLL FLUORESCENCE IN MARINE PHYTOPLANKTON SPECIES

Larry E. Brand

The diel periodicities of *in vivo* chlorophyll fluorescence and DCMU-enhanced chlorophyll fluorescence of 45 marine phytoplankton species were examined for two days in a 14:10 light:dark cycle and then in continuous light for another two to three days. Almost all phytoplankton species exhibit a more rapid increase in *in vivo* fluorescence and DCMU-enhanced fluorescence during the light phase than during the dark phase. Some species show a net decrease in fluorescence at night. Approximately one-half the species examined exhibited persistent diel rhythms in continuous light, indicating the operation of a biological clock. No phylogenetic or habitat related trends as to which species exhibited persistent rhythms were apparent. It is likely that essentially all eukaryotic phytoplankton species have biological clocks, which are expressed under certain conditions. Contrary to past hypotheses, some phytoplankton species are capable of maintaining a persistent diel rhythm in a constant environment while reproducing at a rate greater than one division per day.

Supported by: NSF Grants OCE78-08858 and OCE79-03621.

PERSISTENCE OF CELL DIVISION PHASING IN MARINE PHYTOPLANKTON IN CONTINUOUS LIGHT AFTER ENTRAINMENT TO LIGHT:DARK CYCLES

Sally W. Chisholm and Larry E. Brand

The cell division patterns of 11 species of marine phytoplankton were analyzed in cultures maintained in a 14:10 light:dark cycle followed by three days of continuous illumination. All species except two diatom clones showed "typical" phased or synchronized division on the light:dark regime, although the timing of division relative to the light:dark cycle was variable. In six of the species, the division rhythm persisted throughout the three days of constant light, suggesting endogenous control. In others, it either damped out after one day, or, in the case of the two diatoms, was never evident.

Persistence in constant conditions appeared to be correlated with growth rate to some extent, but not to taxonomic grouping, or timing of division on light:dark cycles.

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SEASONAL DEVELOPMENT OF SUBSURFACE CHLOROPHYLL MAXIMA IN SLOPE WATER AND NORTHERN SARGASSO SEA OF THE NORTHWESTERN ATLANTIC OCEAN

James L. Cox, Peter H. Wiebe, Peter Ortner and Steven Boyd

Seasonal trends in the vertical distribution of chlorophyll *a* in Slope Water and the northwestern Sargasso Sea are analyzed using data from a variety of sources, published and unpublished. Both Slope Water and Sargasso data indicate a seasonal submergence of the chlorophyll maximum, and the formation of a summer to early fall deep chlorophyll maximum (DCM). Mechanisms of formation of the DCM appear to differ in the two regions, as evidenced by differences in the degree of light penetration at the maximum, timing of DCM formation, abundance of chlorophyll, temperature at the maximum, and relationships between DCM parameters. Correlations between these parameters (DCM

depth, DCM chlorophyll concentration, integral chlorophyll, nitracline depth, nitrate maxima depth, pycnocline depth) are generally high for data from both regions combined, and in Slope Water alone. Correlations for Sargasso data alone are all nonsignificant, except for DCM depth vs. nitracline depth. Implications of the data for interpreting correlations between DCM parameters in different hydrographic regimes are discussed.

In press: Journal of Biological Oceanography.

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A MODEL OF ANNUAL PLANKTON CYCLES

Geoffrey T. Evans and John S. Parslow

Differential equation models of spring plankton blooms cannot by themselves predict plankton concentrations: they can only predict how any arbitrarily prescribed concentrations will change. A bloom then occurs as much because there were pre-bloom conditions as because the equations were right. If we ask "Why is there an annual cycle of bloom and decay?" instead of "Why is there a bloom?", and examine the steady cycle which is approached from almost all initial conditions, then a very simple model, with slowly varying parameters, can account both for the occurrence of a spring bloom in many areas, and for the lack of one in the Subarctic Pacific.

Supported by: Pew Memorial Trust and NOAA Sea Grant NA80AA-D-00077.

COMPARATIVE RAPID AMMONIUM UPTAKE BY FOUR MARINE PHYTOPLANKTON SPECIES

Joel C. Goldman and Patricia M. Glibert

Four marine phytoplankton species - the chlorophyte *Dunaliella tertiolecta* (Dun) and the diatoms *Phaeodactylum tricornutum* (TFX-1), *Chaetoceros simplex* (BBsm), and *Thalassiosira weissflogii* (Actin) - were first maintained at various steady state growth rates μ at 12°, 16° and 20°C in NH_4^+ -limited continuous cultures and then pulsed with saturating level of $^{15}\text{NH}_4^+$. Based on a series of time-course and 5-minute single end-point measurements of the maximum specific NH_4^+ uptake rate $\hat{V}$, we found that the duration of incubation and the physiological state of the cell populations were the major determinants of enhanced

NH_4^+ potential, that is, NH_4^+ uptake rates that exceed the growth rate. *P. tricornutum* and *T. weissflogii* displayed the greatest enhanced uptake potential when μ was about 25 percent of $\hat{\mu}$, the maximum specific growth rate. Under these conditions the relative maximum uptake rate $\hat{V}_5/\hat{\mu}$, for 5 min durations was ~15 to 20. Even at high μ (0.80 to 0.95 $\hat{\mu}$) the ratio $\hat{V}_5/\hat{\mu}$ for *P. tricornutum* and *T. weissflogii* along with *C. simplex* was elevated between 5 and 8, indicating that enhanced NH_4^+ uptake for short periods is possible even when phytoplankton are near nutrient-saturated. The effect of temperature on NH_4^+ uptake was manifested primarily as changes in the nitrogen cell quota Q so that the cellular transport rate ρ for NH_4^+ , but not the ratio $\hat{V}/\hat{\mu}$, was temperature-dependent. The time-dependency of NH_4^+ uptake was most evident by the fact that $\hat{V}$ decreased dramatically with incubation period even over the first minute of incubation and that uptake ceased within 1 to 2 hours. Uptake rates over the first seconds of incubation were so high as to suggest that frequent, but short-lived, exposures to micropatches of NH_4^+ in the marine environment may be a way for phytoplankton to overcome molecular diffusion limitations on the persistence of nutrient microzones.

Supported by: NSF Grants OCE79-19420 and OCE80-24445.

EFFECT OF NITROGEN-MEDIATED CHANGES IN ALKALINITY ON pH CONTROL AND CO_2 SUPPLY IN INTENSIVE MICROALGAL CULTURES

Joel C. Goldman, Mark R. Dennett and Carol B. Riley

The freshwater algae *Scenedesmus obliquus* was grown in continuous culture at a fixed dilution rate of 0.5/day, but at varying pH in the range 4.17 to 10.67. The pH was regulated in the range 4.17 to 7.67 by continuously bubbling 1 percent CO_2 -enriched air into the cultures and by varying the source of nitrogen (NO_3^- , NH_4^+ or urea) in the growth medium, which, in turn, led to changes in culture alkalinity. Culture alkalinity and PCO_2 were the sole determinants of pH. A pH-stat system, together with NO_3^- in the medium, was used to regulate the pH in the range 7.92 to 10.67. Maximum productivity, which occurred at pH 6.6, was dependent on N source only to the extent that culture alkalinity was a function of nitrogen uptake. The results demonstrate that the choice of N is a critical factor in controlling the pH of large-scale algal cultures. NH_4^+ is a poor source of N because it leads to destruction of culture alkalinity and concomitant growth-

inhibiting reductions in pH, whereas NO_3^- has an opposite effect, although pH is not so severely affected in this case. Urea is, by far, the most suitable N source for maximizing algal yield when it is supplied in combination with the proper amounts of HCO_3^- alkalinity in the growth medium and % CO_2 in the bubbled gas that will lead to an equilibrium pH near the optimum pH.

In press: Biotechnology and Bioengineering.

Supported by: Solar Energy Research Institute Subcontract XR-9-8144-1 and NOAA Sea Grant NA80AA-D-0077.

MARINE PHYTOPLANKTON PHOTOSYNTHESIS AND TRANSIENT AMMONIUM AVAILABILITY

Joel C. Goldman, Mark R. Dennett and Carol B. Riley

Based on a series of 38 short-term incubations with four marine phytoplankton species pre-cultured in NH_4^+ -limited continuous cultures at varying temperatures and growth rates, we found that the specific rate of ^{14}C uptake was unaffected by NH_4^+ enrichment. These results support the findings of others that short-term enrichment bioassays provide inconclusive evidence regarding the type and degree of nutrient limitation present. Moreover, phytoplankton, when faced with pulsed NH_4^+ additions as might occur during exposure to a micropatch of elevated NH_4^+ , probably maintain constant photosynthetic rates even though they may rapidly incorporate the available NH_4^+ . Although increased respiration is known to accompany rapid NH_4^+ uptake by nitrogen-starved cells, such conditions may not exist in dynamic oligotrophic and other marine waters in which growth rates are high enough so that varying degrees of nitrogen limitation, but not nitrogen-starvation, prevail.

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NONLINEAR TIME-COURSE UPTAKE OF CARBON AND AMMONIUM BY MARINE PHYTOPLANKTON

Joel C. Goldman, Craig D. Taylor and Patricia M. Glibert

In a series of laboratory and field experiments with natural and cultured marine phytoplankton the shapes of the time-dependent uptake curves of

$^{15}\text{NH}_4^+$ and $\text{H}^{14}\text{CO}_3^-$ were determined. Non-linearity in ^{14}C uptake in laboratory cultures did not appear to be a function of steady state growth rate. However, temperature did appear to affect the degree to which ^{14}C is incorporated in a linear manner for *Thalassiosira weissflogii*, but not for other species investigated. Deviations from linearity for both $\text{H}^{14}\text{CO}_3^-$ and $^{15}\text{NH}_4^+$ uptake in both laboratory and field experiments appeared to be directly related to NH_4^+ depletion, especially where NH_4^+ levels at the start of the incubations did not exceed a few tenths $\mu\text{g atom l}^{-1}$. The distribution of C and N among subcellular components was also investigated during the field experiments. The results demonstrated that by analyzing compositional changes among subcellular components a much improved estimate of the metabolic state of confined phytoplankton may be obtained. Our results demonstrated that there are severe incompatibilities between choosing an incubation period based solely on analytical requirements from one based on the best representation of the time scale of physiological responses by phytoplankton. Time-course experiments allow us to better understand the short-term responses by phytoplankton, environmental influences on uptake, such as light and temperature, and to identify analytical problems or bottle effects, such as nutrient depletion.

Published in: Marine Ecology Progress Series.

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TEST FOR ALLELOPATHIC INTERACTIONS BETWEEN TWO MARINE MICROALGAL SPECIES GROWN IN INTENSIVE CULTURES

Joel C. Goldman, Mark R. Dennett and Carol B. Riley

Both high pH and cell senescence are believed to lead to the production of toxic extracellular metabolites in freshwater microalgae. However, there was no evidence for allelopathic suppression of photosynthesis when filtrates of either of two marine microalgae, *Phaeodactylum tricornutum* and *Dunaliella tertiolecta*, were mixed with whole cultures of the other species. This result occurred even when filtrate of *P. tricornutum* sample was derived from a culture at high pH or from one in varying stages of senescence. It is believed that the major factor leading to the dominance of *P. tricornutum* in intensive outdoor cultures is the unique ability of this alga to tolerate pH levels above 9.5 and not to allelopathic inhibition of competing species.

In press: Current Microbiology.

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THE EFFECT OF pH IN INTENSIVE MICROALGAL CULTURES. I. BIOMASS REGULATION

Joel C. Goldman, Joseph Azov,
Carol B. Riley and Mark R. Dennett

Two freshwater and two marine algal species were grown in intensive continuous cultures at a fixed dilution rate of 0.5 day⁻¹, but at varying pH levels in the range 7.6 to 10.6. Both freshwater species, *Scenedesmus obliquus* and *Chlorella vulgaris*, grew up to pH 10.6 although *C. vulgaris* was more adversely affected by alkaline pH than was *S. obliquus*. Of the marine species, *Phaeodactylum tricornutum* hardly was affected by varying pH up to its maximum tolerable level of 10.3, whereas growth of *Dunaliella tertiolecta* was adversely affected by increasing pH and ceased when the pH exceeded 9.3. These results are consistent with the general observations that most marine species can not tolerate alkaline pH values much above 9.5. Moreover the unique ability of *P. tricornutum* to grow at pH > 10 probably is a major factor contributing to its well-documented success in large-scale outdoor cultures that are poorly buffered. It is difficult to separate metabolic from purely chemical factors that influence the pH tolerance limits of the individual species. However, the lower pH limits distinctly were controlled by the production of alkalinity concomitant with NO₃ uptake, whereas the upper pH limits in the case of *S. obliquus* and *P. tricornutum* seemed to be regulated primarily by metabolic control. In no case was the availability of inorganic carbon an influencing factor in setting the maximum attained pH.

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THE EFFECT OF pH IN INTENSIVE MICROALGAL CULTURES. II. SPECIES COMPETITION

Joel C. Goldman, Carol B. Riley
and Mark R. Dennett

The results of a series of competition experiments between the chlorophyte *Dunaliella tertiolecta* (Dun) Butcher and the diatom *Phaeodactylum tricornutum*

(TFX-1) Bohlin demonstrate conclusively that *P. tricornutum* dominates in intensive marine cultures when the pH rises above ~10. This dominance results because of the diatom's unique ability among marine species to tolerate alkaline conditions. When the pH is regulated both freshwater and marine algae, once firmly established in culture at their respective pH optima, can resist invasion from competing species. Hence, pH control may be a method for maintaining species other than *P. tricornutum* in mass culture. However, when *D. tertiolecta* is grown under even slight pH stress it becomes susceptible to invasion by *P. tricornutum*. This susceptibility to takeover by *P. tricornutum* increases with increasing pH. In contrast, the freshwater chlorophyte *Chlorella vulgaris* Beij., which also is sensitive to increasing pH, is capable of remaining dominant at any pH within its tolerance range when invaded by the pH-insensitive chlorophyte, *Scenedesmus obliquus* (Turp.) Kutz. Although allelopathic interactions may be responsible for the success of *C. vulgaris* under seemingly stressful conditions, the success of *P. tricornutum* at increasingly higher pH seems to be related primarily to the alga's pH tolerance characteristics and not to any chemical interactions with competing species.

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EQUIVALENCE AND THE ADAPTATIONIST PROGRAM

Edward M. Hulburt

The equivalent form of 'if species x responds to year-round temperatures then it is adapted to them' is 'if it is not adapted to year-round temperatures then it does not respond to them.' The traditional adaptationist would find 'not adapted' unacceptable, insisting that a species is adapted to whatever range of temperature it responds to. But the reformed adaptationist, it is felt, would welcome the structure of logic on which his data may be mapped, insuring thereby a legitimate comparison of species which are adapted with those which are not.

In press: Oikos.

Supported by: WHOI.

FROM A PLANKTONIC POINT OF VIEW, ADAPTATION

Edward M. Hulburt

Through the use of logical equivalence, species may be separated into those which are adapted to certain conditions and those which are not adapted to these conditions. The conditional 'if x is adapted to conditions of the southwestern North Atlantic then x does not have marked responsiveness' is equivalent to 'if x does have marked responsiveness, then x is not adapted to these conditions.' Instances of these are gotten by letting x be any species except Coccolithus huxleyi in the first conditional and by letting x be C. huxleyi in the second conditional.

In press: The American Naturalist.

Supported by: WHOI.

FROM A PLANKTONIC POINT OF VIEW: SPATIAL STRUCTURE, THE MEDIATION OF CHANGE, AND COMPETITION

Edward M. Hulburt, Mary Russell
and Farideh Mahmoodian

There is an abundance of empty places for the phytoplankton species to change in at Bushehr, Iran. The changes are uncompetitive, desultory and devoid of tendency toward exclusion. But mussel clumps on California pilings, composed often of two species, show a tendency toward exclusion of one species, though not uncomplicated by a reverse tendency reestablishing the two. Even in this tightly packed situation there seem to be empty places to mediate the changes. A logic model is brought in, helping to define the felt impossibility of exclusion in all mussel clumps, and thus guarantee competition between the two species of mussels for empty places. During the course of evolution there was a change from the uncompetitiveness of the phytoplankton to the competitiveness of mussels. But competitiveness was purely accidental, being contingent on the mussel's solid substrate and on an excess of food.

In press: Evolutionary Theory.

Supported by: WHOI.

THE ADAPTATION OF MARINE PHYTOPLANKTON SPECIES TO NUTRIENT AND TEMPERATURE

Edward M. Hulburt

Two cases where adaptedness is compared to unadaptedness are taken up. In the

first case, two types of phytoplankton are inherently different but occur under the same conditions, so that if one is adapted then the other is not. Thus, if there are species which have limited capability for growth and conform thus to low nutrients regions, are adapted, then there are species which by having a less limited capacity for growth are not adapted to low nutrients of such regions. But this rating of the second species as being inherently unadapted depends on the first's not forcing the second into an unadapted state by keeping nutrient low -- a claim that is taken up in considerable detail.

In the first case the plankton is split into mutually exclusive and jointly exhaustive fractions. But in the second case logical equivalence is used. If population x has a temperature response range equal to an environmental range and occurs throughout that range, then it is adapted to that temperature range. This is equivalent to: if population x is not adapted to that temperature range but does have a matching response range, then it does not occur throughout that range; or if population x is not adapted to that temperature range but does occur throughout the range, then it does not have a matching response range. Experimental and observational data justify these equivalences.

In press: Oecologia.

Supported by: WHOI.

THE CAPACITY FOR CHANGE AND THE UNPREDICTABILITY OF THE PHYTOPLANKTON OF THE EAST COAST OF THE UNITED STATES

Edward M. Hulburt

Differences in the degree of change from time to time through the year and place to place along the U.S. east coast show Skeletonema costatum to have a greater capacity for change than Thalassionema nitzschioides. These differences stand in contrast to the unpredictable occurrence and absence of Skeletonema and a number of other species from time to time through the year and from year to year at Woods Hole and from place to place along the U.S. east coast. Skeletonema's greater capacity for change than Thalassionema's transmits an inherently variable capacity for change to the whole phytoplankton, and the unpredictability of the constituent species transmits this characteristic to the whole phytoplankton too.

In press: Journal of Plankton Research.

Supported by: WHOI.

THE UNPREDICTABILITY OF THE MARINE PHYTOPLANKTON

Edward M. Hulburt

The focus of this paper is on what appears to be a large and partly inherent measure of unpredictability in marine phytoplankton species. Thus, if a species is frequently abundant and occasionally rare or if instead it is frequently rare and occasionally abundant, it is unpredictable in its occasional failure or in its occasional success. The close spatio-temporal juxtaposition of patches of abundance of a given species, >3.0 cells/cm³, with patches of rarity, <0.03 cells/cm³, under conditions of excess nutrient often, attest to its fast-growing but unpredictable behavior. Such species occur in the slope water off the coast of southern New England. Farther away, in the mid-Atlantic, slowly growing predictable species occur. So, schemes of unpredictability and predictability as approximate mirror images are presented. In conclusion, a theoretical construct in terms of a single species is given.

In press: Ecology.

Supported by: WHOI.

RESONANCE, PREY-PREDATOR MODELS AND PLANKTON BLOOMS

Steven H. Strogatz and Geoffrey T. Evans

In ecological models of interacting species with periodically varying parameters, very large population fluctuations can occur at some intermediate period of variation. This phenomenon is like resonance in a damped linear oscillator, with extra complications (even in linear approximations) due to parametric excitation. Spring phytoplankton blooms may be a resonance phenomenon.

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Thoracosphaera heimii (LOHMANN) KAMPTNER IS A DINOFLAGELLATE: OBSERVATIONS ON ITS MORPHOLOGY AND LIFE CYCLE

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

Thirty clones of Thoracosphaera heimii (Lohmann) Kamptner have been isolated and cultured from oceanic waters of the western North Atlantic and Gulf of Mexico. Observations on the life cycle and

morphology of one clone isolated from the Sargasso Sea are reported herein. The calcareous cell wall is present in the coccoid, vegetative life phase. Reproduction is accomplished by the formation of transitory aplanospore or planospore stages or occasionally by binary fission of weakly calcified cells. The planospore is non-thecate and Gymnodinium-like with an undulating transverse flagellum and a whip-like longitudinal flagellum. All life stages possess chloroplasts and a nucleus with continually condensed chromosomes. The planospore morphology and the dinocaryotic nucleus demonstrate that T. heimii is a dinoflagellate and not a coccolithophorid. The taxonomic affinity and classification of T. heimii within the dinoflagellates is discussed, and a new order, Thoracosphaerales Tangen, ord. nov., is proposed for primarily coccoid marine dinoflagellates that possess a calcified cell wall in the vegetative life phase.

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INSTRUMENTATION FOR THE IN SITU, TIME-COURSE MEASUREMENTS OF PHYTOPLANKTON PRODUCTION

Craig D. Taylor, John J. Molongoski,
Kenneth W. Doherty and Per O. Ljungdahl

As an alternative to the standard end point procedures for measurement of phytoplankton production, automated instrumentation has been developed that performs time-course incubation experiments directly in situ where natural conditions of temperature, light, hydrostatic pressure, etc. can be maintained. The sampler incubation device (SID) procures a one-liter sample from the water column and simultaneously introduces an appropriate radiotracer. During subsequent in situ incubation, 50 ml subsamples are withdrawn from the main incubating sample at equally spaced time intervals and preserved for laboratory analysis.

Estuarine field studies demonstrated the use of the SID for conducting in situ time-course studies of the short-term dynamics of phytoplankton photosynthesis. Representative experiments conducted using the SID revealed rapid phytoplankton growth resulting in non-linear carbon uptake within 0.5-1.0 hour, emphasizing that end point analyses of even short duration can lead to large errors in estimating phytoplankton production rates. Comparison of these data with theoretical growth equations indicated a specific growth rate of 0.23 hr⁻¹. Linear carbon uptake was observed in additional SID experiments and appeared to be correlated with periods of

relatively higher productivity and greatly reduced growth rates. Studies of the rapid fluctuation in phytoplankton activity resulting from large order, cloud-induced variations in light intensity, and the application of cellular fractionation methods for measuring the intracellular distribution of newly fixed carbon illustrated the utility of timecourse techniques for studying phytoplankton physiology and community metabolism in situ.

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REGULATION OF GROWTH IN AN ESTUARINE CLONE
OF *Gonyaulax tamarens* LEBOUR:
SALINITY-DEPENDENT TEMPERATURE RESPONSES

Carl J. Watras, Sallie W. Chisholm
and Donald M. Anderson

Batch-culture experiments with *G. tamarens* indicated variations in population growth rate and cell size as a function of temperature and salinity. The data on population growth were used to develop a simple model which predicts bloom development in the absence of other regulatory factors. The agreement between observed and predicted results is quite good for field populations of *G. tamarens* in Cape Cod estuaries during 1977 and 1980. Although other factors may undoubtedly complicate population dynamics, this agreement indicates that in some cases one can account for the development of blooms in this region simply on the basis of salinity dependent temperature regulation of population growth.

In our cultures, cell size was found to change with population growth rate; small cells dominated in populations growing rapidly. However, the larger cell size in the slower growing cultures failed to compensate for the reduced population growth rates when rates of biosynthesis were compared. The potential use of cell size variability in estimating in situ growth rates, and its role in bloom decline through size-selective grazing by zooplankton are considered.

In press: Journal of Experimental
Marine Biology and Ecology.

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PLANT PHYSIOLOGY

TRACER STUDIES OF GAS CIRCULATION IN
NUPHAR: $^{18}\text{O}_2$ and $^{14}\text{CO}_2$ TRANSPORT

John W. H. Dacey and M. J. Klug

A flow-through ventilation system operates in the yellow waterlily, delivering O_2 to its roots and rhizomes, and CO_2 to its emergent leaves. The flow of air into the youngest emergent leaves and down their petioles to the rhizome is confirmed by $^{18}\text{O}_2$ and C_2H_6 tracer experiments, showing that most of the O_2 in the rhizome originated in the atmosphere. This flow of air into the rhizome forces a simultaneous gas flow from the rhizome up the petioles of the older emergent leaves to the atmosphere. Radiolabeled CO_2 was used to demonstrate that CO_2 present in the gas moving up these petioles was fixed in the efflux leaves. This experiment yielded an estimate of phloem transport rates in petioles of photosynthesizing leaves.

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VENTILATION BY FLOATING LEAVES IN *Nuphar*

John W. H. Dacey and M. J. Klug

The network of internal gas spaces in the yellow waterlily constitutes a pressurized flow-through system which forces oxygen to the rhizome buried in the anaerobic sediment. This ventilation has been documented previously in a subspecies of *Nuphar luteum* with aerial leaves, and was found to be dependent on the warming of influx leaves by sunlight. In this study we have found the ventilation system operating in two different subspecies of *N. luteum* growing in Alaska and in Massachusetts. These plants have floating leaves so that during certain times of the year the leaves are warmed by the lake water and the ventilation continues during both daylight and darkness.

In press: American Journal of Botany.

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EVAPOTRANSPIRATION OF SOME AQUATIC
MACROPHYTES: RELATION TO CANOPY
CHARACTERISTICS, SEASON AND PRODUCTIVITY

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

Relationships of plant canopy structure, season and net productivity to the evapotranspiration of the freshwater macrophytes *Eichhornia crassipes* (Mart.) Solms, *Hydrocotyle umbellata* L. and *Lemna minor* L. were examined in tank cultures at Ft. Pierce, Florida. Respective evapotranspiration to open water evaporation ratios (E/E_o) for these species maintained at fixed densities averaged 1.7, 1.8 and 0.9 for the year 1979. Water losses from all cultures varied seasonally, with highly significant correlations between incident solar radiation, evaporation and evapotranspiration. Correlations between evapotranspiration and plant productivity of *Eichhornia* and *Lemna* were also significant. However, measurements of water loss and yields at various plant densities indicate that evapotranspiration is not dependent on net productivity.

Evapotranspiration of *Eichhornia* fluctuated by as much as 40 percent when its canopy morphology was varied by changing plant density. Water loss from tanks containing *Lemna*, a species which exhibits mainly two-dimensional growth, remained constant when plant density was varied. These data confirm that seasonal variability, and for many species variations in canopy morphology, should be considered when estimating evapotranspiration of aquatic macrophytes over a large temporal or areal basis.

In press: Aquatic Botany.

Supported by: Solar Energy Research
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NITROGEN UPTAKE AND STORAGE BY THE RED ALGA
Gracilaria tikvahiae

John H. Ryther, Nathaniel Corwin,
Thomas A. DeBusk and L.D. Williams

Nitrogen-starved plants of the red alga *Gracilaria tikvahiae* assimilate ammonium-nitrogen very rapidly, doubling their total tissue nitrogen content in eight hours or less. Uptake of nitrate-nitrogen is less rapid. Ammonium uptake is initially the same in the dark as in full sunlight, but illuminated seaweeds continue to assimilate the nitrogen longer. N-starved plants soaked in a full nutrient medium including NH_4-N for as little as six hours and returned to unenriched flowing seawater

will grow at a non-nutrient-limiting rates for as much as two weeks before they again become nutrient-deficient and their growth rate declines.

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SIGNIFICANCE OF CARBON DIOXIDE AND
BICARBONATE-CARBON UPTAKE IN MARINE
BIOMASS PRODUCTION

John H. Ryther and Thomas A. DeBusk

The red alga *Gracilaria tikvahiae* is capable of extremely high rates of biomass production (>20 g vs/m^2 -day or 74 mt vs/ha -yr), but such yields require rapid seawater exchange rates (25 culture volumes/day) that would be uneconomical and non-energy cost-effective in a land-based or coastal energy farm based on pumped water.

The requirements for high seawater exchange reflect CO_2 limitation which is exacerbated in species such as *Gracilaria* that cannot utilize bicarbonate as a substrate for photosynthesis, since free CO_2 is almost unavailable at the high pH levels (>9.0) attained in dense cultures at low exchange rates. Bicarbonate users, such as *Ulva*, are better adapted to growth under such relatively stagnant conditions where CO_2 is not rate-limiting.

At extremely low seawater exchange rates (<1 exchange/day) even CO_2 may become growth limiting and high yields depend upon CO_2 -enrichment.

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RELATIONSHIPS BETWEEN CULTURE DENSITY AND
THE COMPOSITION OF THREE FLOATING
AQUATIC MACROPHYTES

Craig S. Tucker

Eichhornia crassipes (Mart.) Solms, *Pistia stratiotes* (L.) and *Lemna minor* (L.) were cultured at four different densities each and analyzed for cell-wall fraction, crude protein, total available carbohydrate

and ash. Cell-wall fraction increased and crude protein content decreased as density increased in Eichhornia and Pistia cultures. The cell-wall and crude protein content of Lemna did not change with increasing culture density. Differences in the trends of cell-wall and crude protein content of the three plants at increasing culture densities appear to be related to differences in growth form. There was no difference in the total available carbohydrate or ash content of the three species at different culture densities.

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POPULATION DYNAMICS

ON THE COMPARATIVE ALLOCATION OF BIOMASS ENERGY AND NUTRIENTS IN PLANTS

Warren G. Abrahamson and Hal Caswell

The objective of this study was to test the assumption that biomass allocation, energy allocation and nutrient element allocation are equivalent for studies involving ecological strategy analysis in plants. The results for both semelparous Verbascum thapsus and five iteroparous Solidago species show that the mineral elements examined are allocated differently than biomass. Thus, in a study aimed at estimating the allocation strategy of plants within a population, it would not be safe to measure biomass allocation and assume that it reflected nutrient allocation. More important, there are significant nutrient x population interactions, meaning between-population trends in biomass allocation do not reflect qualitative trends in mineral element allocation. The results of this study do not identify a given mineral element, biomass, or energy as the better measure of resource allocation patterns, but the study indicates that further research along the lines of the "currency" of allocation are greatly needed.

Results with Solidago show strong correlation between biomass allocation and energy allocation. This re-emphasizes Hickman and Pitelka's (1975) conclusion that calorimetry is not necessary to determine energy allocation patterns in populations in plants with primarily carbohydrate seed reserves. There was an overall lack of correlation between soil

nutrients and the chemical composition of Solidago plant organs, or whole plants.

In press: *Ecology*.

Supported by: NSF Grant OCE76-19278.

LIFE HISTORY THEORY AND THE EQUILIBRIUM STATUS OF POPULATIONS

Hal Caswell

Life history traits are often used to distinguish equilibrium from non-equilibrium populations. This is invalid, both within the framework of r- and K-selection theory and within a demographic model which takes age structure into account. In both cases, the patterns favored in an equilibrium population are even more intensely favored in a non-equilibrium population which happens to spend most of its history in a state of population decline. The only characteristic which may serve to distinguish equilibrium populations is a lower absolute magnitude of selective pressure on some traits.

The traits favored in declining populations include long lifespan, slow development, delayed reproduction, iteroparity, low degree of senescence, and relatively high degree of investment in whatever offspring are produced. The traits favored in increasing non-equilibrium populations are largely the opposite: short life, fast development and early reproduction, semelparity, senescence and less investment in individual offspring.

There is an evolutionary instability in the center of the gradient from predominately increasing to predominately decreasing populations. Over evolutionary time, non-equilibrium populations will diverge towards one extreme or the other. Thus, this model predicts the existence of groups with distinctly "declining" (i.e., "K-selected") characteristics, and other groups with distinctly "increasing" (i.e., "r-selected") characteristics. Because the same traits that increase the proportion of its history that a population spends in decline also increase the time required for extinction, the former group will occupy relatively stable habitats, the latter group more disturbed habitats. This requires no equilibrium assumptions; all of the species involved may be losers. The predictions of the model are supported by an analysis of the relation between competitive tolerance, age at first reproduction, and life span in North American trees.

In press: *American Naturalist*.

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OPTIMAL LIFE HISTORIES AND THE AGE-SPECIFIC COSTS OF REPRODUCTION

Hal Caswell

Increases in reproduction at a given age may carry costs measured as reductions in subsequent survival and/or future fertility. Such costs generate constraints within which natural selection may mould life histories to maximize fitness. In this paper, I derive expressions predicting the age-specific costs of reproduction conditional on the maximization of fitness. Survival costs should, on this hypothesis, vary as the inverse of the reproductive value curve; fertility costs should vary as the ratio of successive terms in the stable age distribution. For many organisms, this means that survival costs should increase markedly with age, while fertility costs should be nearly age-invariant. Data on such age-specific costs is scarce, but that which is available (mainly for humans) agrees with these predictions.

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OPTIMAL LIFE HISTORIES AND THE MAXIMIZATION OF REPRODUCTIVE VALUE: A GENERAL THEOREM FOR COMPLEX LIFE CYCLES

Hal Caswell

The theorems on the maximization of reproductive value in optimal life histories were originally stated and proven for age-classified populations. Many organisms, however, are more appropriately classified by other variables, such as size, developmental stage, instar, spatial location, etc. Their life cycles may be considerably more complex than those for which classical demographic theory was devised. In this paper, I show how to calculate reproductive value for such populations, and give conditions for its maximization. The theory for age-classified populations follows as a special case.

In press: Ecology.

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STABLE POPULATION STRUCTURE AND REPRODUCTIVE VALUE FOR POPULATIONS WITH COMPLEX LIFE CYCLES

Hal Caswell

Classical demographic theory was developed to describe age-classified populations, in which knowledge of an individual's age accurately specifies its

demographic state. In many species (e.g., plants, insects, fish) individuals of the same age may be in very different states; classical theory is inappropriate for such populations. In this paper, I present general formulae for the stable stage distribution (the analogue of the stable age distribution of classical demography) and the stage-specific reproductive value distribution for populations with arbitrarily complex life histories. The results are obtained by use of the z-transforms of a simple graphical representation of the life cycle. They yield literal formulae, which can be used to draw qualitative conclusions about the general properties of the life history. They will also provide quantitative results if numerical values for the parameters are available. Since the selective pressures on life history traits can be expressed simply in terms of the stable stage distribution and reproductive value, these results render complex life cycles amenable to evolutionary analysis. The reproductive value formulae can sometimes be used to calculate optimal schedules of stage-specific reproductive effort.

In press: Ecology.

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THE TIME REQUIRED FOR COMPETITIVE EXCLUSION

Hal Caswell

The time required for local competitive exclusion plays an important role in theories of non-equilibrium coexistence. It has been hypothesized that environmental fluctuations on the same time scale as this exclusion time may lead to long-term non-equilibrium coexistence. This paper examines the factors determining exclusion time in a two species system described by the Lotka-Volterra competition equations. The most important parameters are the intrinsic rate of increase of the losing competitor and the competition coefficient giving the effect of the winning competitor on the loser. Interactions involving exploitation competition between very similar large long-lived species lead to very long exclusion times. In general, exclusion is expected to require tens of generations, unless intense interference competition is involved. This agrees with the results of laboratory experiments. These results are applied to the highly diverse communities in tropical rain forests and in the deep sea.

Supported by: NSF Grant OCE76-19278.

LINEARIZING ECOLOGICAL MODELS WITH TIME-VARYING PARAMETERS

Geoffrey T. Evans

An ecological model with time varying parameters can be linearized about a point which is either a local equilibrium, or fixed in time, but not in general both. Each choice has its advantages. The resulting linear models have variable coefficients, and therefore lack some of the attributes of linear models with constant coefficients; for example, they can react to a sinusoidal input in a very non-sinusoidal way. Linearizations of a model of annual plankton cycles can capture much of the behavior of the original nonlinear model.

Supported by: NOAA Sea Grant NA80AA-D-00077.

SALT MARSHES

GRAZING BY CANADA GEESE AND RELATED ASPECTS OF THE CHEMISTRY OF SALT MARSH GRASSES

Robert Buchsbaum, Ivan Valiela
and John M. Teal

Feeding selection by Canada geese is a complicated phenomenon in which plant chemistry, structure and apparency all play a significant role. We have studied the influence of phenolic acids, nutrient enrichment and translocation of plant substances on the feeding of Canada geese on the salt marsh grass, *Spartina alterniflora*. Ferulic acid, a phenolic acid present in high concentrations in *S. alterniflora*, inhibits feeding by captive geese when added to the food. Additionally, geese have been observed to forage selectively in fertilized marsh plots where the vegetation is not only higher in nitrogen but also lower in phenolic acids when compared to control plots. Phenolic acids from marsh plots are important in determining seasonal and spatial grazing patterns of geese on marshes. Geese feed mostly on the distal leaf tips of *S. alterniflora*, the parts of the leaf that are higher in nitrogen than other parts of the plant, indicating that high nitrogen content can mask the repellent effects of the relatively higher concentrations of phenolic acids present in the leaf tips.

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

HEAVY METAL TOLERANCE IN A SALT MARSH MICROBIAL COMMUNITY RECEIVING INPUTS OF HEAVY METALS

Anne E. Giblin, Michael Piotrowski,
Bruce Leighty, Ivan Valiela and John M. Teal

Addition of a heavy metal containing sludge fertilizer to experimental salt marsh plots increased both the nitrogen and the heavy metal content of the surface sediments. Aerobic heterotrophic microorganisms collected from these plots differed from microbes collected from control plots in their oxygen uptake rates on a uniform sediment media in the presence and absence of metals. When metals were not present, microbes from fertilized plots took up significantly less oxygen than microbes from control plots. In the presence of metals oxygen uptake by microbes from both plots was depressed. However, activity of microbes from the fertilized plots was significantly less inhibited than microbes from the control plots, indicating a greater degree of metal tolerances.

In order to assess the effect of metals in the absence of nutrient enrichments, chromium solutions were applied to several one-m² marsh plots. Microbes from these plots developed a tolerance to both Cu and Cr within one month. The oxygen uptake on sediment media in the absence of metals did not differ from non-metal tolerant microbes. It appears that microbes from the fertilized plots have adapted to the high nutrient and metal conditions found on the experimental plots.

Supported by: NSF Grant DEB-7905127 and NOAA Sea Grant 04-8-M01-149.

ROLE OF PREDATORS AND FOOD RESOURCES IN REGULATING THE MACROBENTHOS OF SALT MARSH CREEKS

Wendy I. Wiltse, Kenneth H. Foreman,
John M. Teal and Ivan Valiela

Effects of nutrient additions and predator exclosures on the density and species composition of benthic macroinvertebrates were studied at Great Sippewissett Marsh, Massachusetts. Cages that excluded predators were placed in two urea fertilized and two control tidal creeks in late May and sampled over a 15-week period.

In uncaged creek bottoms densities of macroinvertebrates peaked during the first five weeks then declined 7 to 77-fold by late summer. Densities inside cages increased by 1.3 to 6-fold and remained high through the summer. Sediment

characteristics and partial cage controls indicate that sedimentary modifications by cages per se were unimportant. Concentrations of chlorophyll *a* were significantly less in uncaged sediments than inside cages. Intense generalized predation and grazing by fish and crabs depleted macrofauna and benthic algae in creeks during summer.

The fertilizer treatment appeared to improve the food value of sediments for deposit feeders. However, no increase in biomass or density of macrofauna occurred even inside cages, suggesting that competition for food did not limit macrofaunal population sizes. Fertilization did prompt changes in species composition. The macrofauna in control creeks was dominated by a polychaete, *Streblospio benedicti*, and averaged more species per sample than fertilized creeks where no oligochaete, *Paranais litoralis*, predominated.

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ZOOPLANKTON

PELAGIC TUNICATES: UNIQUE HERBIVORES IN THE MARINE PLANKTON

Alice L. Alldredge and Laurence P. Madin

The pelagic tunicates including salps, doliolids and appendicularians exhibit higher feeding rates, greater retention of bacteria-sized food and much shorter generation times than other marine planktonic herbivores. Their many unique adaptations enable them to reach high population densities and react with maximum flexibility to the unpredictable and patchy environment of the pelagic ecosystem.

Supported by: NSF Grant OCE80-24441.

THE ROLE OF ZOOPLANKTON IN THE ACCUMULATION AND DEPOSITION OF DUPONT EDGEMOOR WASTE (AN ACID-IRON WASTE) AT DEEPWATER DUMPSITE 106

Judith M. Capuzzo

DuPont Edgemoor waste is an acid-iron waste derived from titanium dioxide production; approximately 0.3 million metric tons are dumped annually at Deepwater Dumpsite 106. The waste is a highly acidic solution of ferric chloride containing relatively high levels of several trace metals including Cr, V, Pb,

Ni, Cu and Cd. Chemical dispersion studies at the dumpsite indicate that ferric oxide precipitates in the waste plume and other trace metals may become associated with this particulate phase. Ingestion of this particulate phase by copepods has been demonstrated in the laboratory to be a significant route of uptake for the waste derived metals. Accumulation of the various metals by exposed copepods ranged from 10.8 percent above control values for Fe to 54.7 percent for Cu. The ratios of the various trace metals relative to Fe were slightly enhanced in exposed copepods in comparison with control copepods but one to two orders of magnitude higher than the metal ratios of a 10 ppm waste concentration. Enhancement of metal concentrations in fecal pellets produced by exposed copepods ranged from 25.0 percent above control values for Fe to 60.3 percent for Cu. Metal deposition through fecal pellet production appears to be an effective means of depurating Fe, Pb, Ni and Cu by copepods exposed to Edgemoor waste but Cd could not be detected in fecal pellets. The increased density of fecal pellets compared to the ferric oxide particles could result in a more rapid sinking rate of waste derived metals to the deep ocean. The flux of waste derived metals through zooplankton biomass and the contribution of zooplankton in the biogeochemical cycling of metals at Deepwater Dumpsite 106 is discussed.

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RESPONSES OF ZOOPLANKTON POPULATIONS TO INDUSTRIAL WASTES DISCHARGED AT DEEPWATER DUMPSITE 106 AND THEIR USEFULNESS IN ESTIMATING ASSIMILATIVE CAPACITY

Judith M. Capuzzo and Bruce A. Lancaster

Biological effects of waste disposal to plankton populations can only be evaluated in light of adequate information on the chemical composition of dumped wastes, their persistence in the vicinity of a dumpsite, their bioavailability and bioaccumulation, and their toxicological effects. Through laboratory and field investigations the responses of zooplankton populations to waste additions at Deepwater Dumpsite (DWD) 106 have been evaluated through observations on survival, metabolism, feeding and egg production.

In laboratory studies with copepods, acute toxic effects of wastes discharged at DWD 106 were detected at concentrations >50-100 ppm of DuPont Grasselli waste and American Cyanamid waste and >5-10 ppm of DuPont Edgemoor waste. Exposure of copepods to sublethal concentrations of

each of the wastes resulted in a reduction in the rates of feeding, metabolism and egg production compared to control animals. Thus the energetics and reproductive potential of zooplankton entrained in waste plumes at DWD 106 may be seriously impaired. In field studies zooplankton collected from a waste plume formed within several hours after an American Cyanamid waste dump showed a disruption in energetics similar to that of laboratory animals. The sublethal effects of the various wastes observed in laboratory and field animals were not reversed to control values when animals were removed from waste exposures and transferred to uncontaminated seawater. Progeny of exposed animals, however, did not retain stress symptoms. Entrainment of zooplankton in waste plumes at DWD 106 appears to be a single short-term event involving only a small percentage of the zooplankton community within this water mass and thus, even with toxic effects well documented, at the present rate of dumping long-term consequences of dumping would appear to be minimal to zooplankton populations at DWD 106.

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Paracandacia worthingtoni A., A NEW
CALANOID COPEPOD FROM THE
SOUTH PACIFIC OCEAN

George D. Grice

A new species of *Paracandacia* from the South Pacific Ocean is described.

THE DEVELOPMENTAL STAGES OF THE CALANOID
COPEPOD *Labidocera wollastoni* (LUBBOCK)
WITH OBSERVATIONS ON ITS EGGS

George D. Grice and Victoria R. Gibson

The developmental stages of *Labidocera wollastoni* are described and compared to those of other species in the genus. Females lay smooth and spiny eggs. Observations on their hatching indicate that smooth eggs are subitaneous and spiny ones are diapause.

THE PRODUCTION, COMPOSITION AND
SEDIMENTATION OF SALP FECAL PELLETS

Laurence P. Madin

Rates of fecal pellet production have been recorded from seven species of oceanic salps feeding on natural diets. Expressed as μgC defecated per mg salp body C per hour, the values range between 3.7 and

27.7. Carbon:nitrogen ratios of the salp fecal pellets average 11.4; the organic matter of the pellets is mainly protein and carbohydrate. Sinking velocities of the pellets are very high, ranging from 320 to 2238 m d^{-1} for pellets from three species. However, the pellets actually sink slower than would be predicted from extrapolation of data for crustacean pellets, due to the shape of the pellets and their density. Calculation of pellet density based on the sinking velocity suggests a mean value of 1.079 g cm^{-3} , substantially lower than for fecal pellets of copepods. The high rates of defecation, large size and rapid sedimentation of salp fecal pellets make them likely mechanisms for rapid transport of small particulate matter from surface waters to deep water and the benthos.

In press: Marine Biology.

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PHOTOPERIODIC AND TEMPERATURE REGULATION
OF DIAPAUSE IN *Labidocera aestiva*
(COPEPODA: CALANOIDA)

Nancy H. Marcus

The calanoid copepod *Labidocera aestiva* was reared in the laboratory to ascertain the effects of photoperiod and temperature on subitaneous and diapause egg production. The results indicate that photoperiod is the primary stimulus regulating the type(s) of eggs produced by a female, but it is also shown that the temperature regime can modify this effect. Under short daylength photoperiods (e.g., 8L:16D), subitaneous egg production was increased by increasing the temperature regime from 15°C or 19°C to 25°C . However, under long daylength (e.g., 18L:6D) regimes, females appear to be unresponsive to temperature changes within the range of 15°C to 25°C . It is suggested that the response of *L. aestiva* to photoperiod and temperature results in a more accurate coupling of the life cycle with seasonal environmental fluctuations.

In press: Biological Bulletin.

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THE REVERSIBILITY OF SUBITANEOUS AND
DIAPAUSE EGG PRODUCTION BY INDIVIDUAL
FEMALES OF Labidocera aestiva
(COPEPODA:CALANOIDA)

Nancy H. Marcus

In Vineyard Sound, Massachusetts, the calanoid copepod, Labidocera aestiva, undergoes a period of facultative diapause that is induced by short daylength photoperiods. This study examines egg production by individual females. It is shown that some if not all females can switch the type(s) of egg produced. The results indicate that, in Vineyard Sound, females adjust to the decreasing daylengths experienced during the fall by switching production from subitaneous to diapause eggs. I suggest that a female is triggered to switch the type of eggs produced after perceiving a specific number of short daylength photoperiods. The conversion is not instantaneous, however, and during this transition phase a female produces both subitaneous and diapause eggs. It is suggested that the reproductive capacity of the population is enhanced by this type of flexible diapause response.

In press: Biological Bulletin.

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METHODS OF DISPERSAL AMONG FOULING
ORGANISMS AND POSSIBLE CONSEQUENCES FOR
RANGE EXTENSION AND GEOGRAPHICAL VARIATION

Rudolf S. Scheltema and James T. Carlton

The spread of fouling organisms is brought about by (1) natural processes such as larval dispersal and rafting, and by (2) various activities of man, especially those related to shipping. Some fouling organisms such as barnacles, attached bivalves and some bryozoa have a planktonic development that extends over several weeks and transport of larvae may play a significant role in the dispersal of such species within estuaries, along coastlines and even in the open ocean. In contrast, ascidians, spirorbid polychaetes and most bryozoa have non-feeding larvae which remain planktonic for only a few hours and their dispersal depends upon rafting and the activities of man. Frequently more than one means of dispersal is involved in the introduction and spread of fouling species into new regions.

The degree of geographic variation to be found among fouling species depends on the one hand upon dispersal capability and the consequent genetic exchange with other

populations and on the other upon natural selection. Genetic variations among widely distributed fouling species, where it has been studied, include such ecologically important characteristics as settlement responses, temperature tolerance and spawning temperature. Such attributes contribute to the intractability of fouling problems and explain why simplistic solutions are not likely to be successful. Methods for the prevention of fouling that ignore dispersal processes and geographic variation are unlikely to provide definitive solutions.

In press: Proceedings of the Marine
Biodeterioration Symposium, J.D.
Costlow, ed., National Institute of
Annapolis.

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GREGARIOUS SETTLEMENT BY THE LARVAE OF
Hydroides dianthus VERRILL 1893
(POLYCHAETA:SERPULIDAE)

Rudolf S. Scheltema, Isabelle P. Williams,
M. A. Shaw and C. Loudon

Larval development of the serpulid polychaete worm, Hydroides dianthus Verrill 1893, parallels that of other closely related species. The larvae prefer to settle upon surfaces already inhabited by other members of their own species rather than to colonize surfaces without such conspecific residents. However, very wide variations in the intensity of settlement are observed. These differences in the amount of settlement cannot presently be attributed to any single variable. Gregarious settlement appears to be typical for sessile species which do not have the ability to reproduce asexually after settlement.

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LABORATORY STUDIES ON THE SIGNIFICANCE OF
TEMPERATURE TO LARVAL SURVIVAL AND LENGTH
OF DEVELOPMENT IN Balanus eburneus
(CRUSTACEA:CIRRIPEDIA)

Rudolf S. Scheltema
and Isabelle P. Williams

The manner in which temperature affects mortality and length of development of Balanus eburneus nauplii is modified by the concentration of unicellular algal food. At 20° and 25°C the mean larval survival

was 63.5 percent and 66.0 percent, respectively, when the algal concentration was 1×10^5 cells ml^{-1} . When the algal concentration was doubled to 2×10^5 cells ml^{-1} , mean survival increased significantly to 92.5 and 96.5 percent at 20° and 25°C, respectively, ($p = 0.002$ at both temperatures). At 30°C the difference in mortality related to algal food concentration disappeared and mean survival was high.

The median length of development to the cyprid stage decreased with increasing water temperature but food concentration markedly modified the median time to complete development. Doubling the amount of algal food at 20°C from 1 to 2×10^5 cells ml^{-1} decreased the time required for development by 3.2 days, approximately equivalent to a temperature increase of 5°C. Higher concentration of algal cells may compensate for low temperature in determining the length of planktonic life of the nauplii.

The effect of temperature on the median time for development was greater at the low than at high food concentrations. At an algal concentration of 1×10^5 cells ml^{-1} , there is a decrease of 6.9 days in the median time for development between 20° and 30°C. When the algal concentration is doubled to 2×10^5 cells ml^{-1} , the decrease in development time over the same temperature interval was only 3.7 days. At 30°C there was no difference in the median time required to reach the cyprid stage. At both 1×10^5 cells ml^{-1} and 2×10^5 cells ml^{-1} only 3.9 days were required. To account for this similarity of development time, it is proposed that optimum feeding rates are already attained at 1×10^5 cells ml^{-1} and that further increase in the numbers of algal cells will not affect the development rate to the cyprid stage.

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EFFECTS OF TEMPERATURE AND LIGHT ON THE FEEDING RATE OF *Favella* sp. (CILIATED PROTOZOA, SUBORDER TINTINNINA)

Diane Stoecker and Robert R. L. Guillard

Laboratory experiments were used to determine the effects of temperature and light on the feeding rate of *Favella* sp., a coastal tintinnid which is a predator on dinoflagellates. At the prey densities of 80-800 dinoflagellates ml^{-1} , clearance rates were relatively independent of temperature between 8 and 20°C with a Q_{10} response of 1.0 to 1.1. Light intensity, prey density, and interactions

between these two parameters had statistically significant effects on clearance rate. In culture vessels, *Favella* aggregates in areas of high prey density. We feel that the effects of light on feeding rate are due to aggregation of the prey and the subsequent aggregation of *Favella* and are thus prey density effects on a microspatial scale.

Supported by: NOAA Grants NA79A-D-00102 and NA80AA-D-00077.

THE EFFECTS OF *Olisthodiscus luteus* CARTER ON THE GROWTH AND ABUNDANCE OF TINTINNIDS

Peter G. Verity and Diane Stoecker

The effects of the red tide flagellate, *Olisthodiscus luteus*, on the growth of two tintinnids, *Tintinnopsis tubulosoides* and *Favella* sp., were measured in batch culture. *Tintinnopsis* and *Favella* grew at rates equivalent to 1.2 (10°C) and 2.0 (20°C) population doublings per day, respectively, when offered nutritionally adequate phytoplankton species. The growth rates of both tintinnids were reduced by the presence of *Olisthodiscus* at concentrations of 10^2 - 10^3 cells ml^{-1} in multi-algal experiments. Growth rate inhibition was proportionately greater at higher *Olisthodiscus* densities. Lethal effects in multi-algal culture were observed for both species at *Olisthodiscus* concentrations of 5×10^3 cells ml^{-1} . *Olisthodiscus* induced mortality of *Tintinnopsis* at all concentrations tested in uni-algal culture. *Olisthodiscus*-conditioned media, however, did not substantially inhibit tintinnid growth when combined with acceptable food species, suggesting that toxicity is induced by ingestion or direct contact with *Olisthodiscus* cells, or from exposure to a short-lived exudate. In agreement with these results, an inverse relationship between *Olisthodiscus* concentration and abundance of natural tintinnid communities was observed in Narragansett Bay, Rhode Island, over a two-year period. The small lorica diameter of the species apparently inhibited by these *Olisthodiscus* blooms, however, suggests a detrimental effect independent of ingestion of cells. In addition to the absolute concentration of *Olisthodiscus* cells, the availability of nutritionally adequate algal food may be an important factor determining the impact of *Olisthodiscus* blooms on tintinnid communities.

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DEPARTMENT OF CHEMISTRY

Geoffrey Thompson, Department Chairman

CHEMISTRY

ORGANIC AND
BIOLOGICAL CHEMISTRY

BACTERIA AND PLUTONIUM IN WATERS
OF THE ALEUTIAN TRENCH

Anne E. Carey

Data are presented showing $239,240\text{Pu}$ concentrations and bacterial abundance, as determined by direct cell counts, in water stations in the Aleutian Trench. No correlations are seen between the data sets, further supporting the hypothesis that bacterial biomass is not a major factor in determining Pu distributions in marine water columns.

In press: Journal of Marine Research.

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BACTERIA AND PLUTONIUM IN
MARINE ENVIRONMENTS

Anne E. Carey and Vaughan T. Bowen

We have looked for correlations, positive or negative, between the concentrations of fallout plutonium and of living bacterial cells in a number of oceanic water or sediment columns. The absence of clear-cut relationships suggests that bacterial biomass cannot be a major variable either in the sedimentation of plutonium downward in the water column, or in plutonium inventories in the sediments. In vitro studies of Pu uptake by cultured sediment bacteria show that the bacterial cell surface is less attractive to Pu in solution than is, for instance, that of diatoms. Arguments are presented suggesting that any relationship between bacteria and Pu must be mediated by physiological and chemical effects.

In press: Limnology and Oceanography.

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SEDIMENT TRAP EXPERIMENT IN THE
EQUATORIAL ATLANTIC OCEAN:
VERTICAL FLUX OF FATTY ACIDS,
REGENERATION AND OXYGEN CONSUMPTION

H. J. W. DeBaar, J. W. Farrington and
S. G. Wakeham

The quantitative and qualitative composition of fatty acids in particulate material collected in traps deployed during 98 days at 389, 988, 3755 and 5068 m depths in the equatorial North Atlantic were determined. The fatty acid composition indicates a marine source (14:0, 16:0, 16:1, 18:0, 18:1, 20:5, 20:4, 22:6, 22:5) with possibly a minor terrigenous component in the bathypelagic traps. The vertical fluxes of fatty acids and lipids decrease rapidly with depth. The rate of net loss of carboxylic acids increases with number of double bonds and decreases with number of carbon atoms. Iso- and anteiso- as well as some monoenic fatty acids are more persistent, probably due to enhanced microbial synthesis during settling which counteracts degradation.

Regeneration of organic C, H, N during settling departs slightly from the Redfield-ratio with increasing depth. Model calculations using flux gradients of organic matter show that about 20-40 percent of oxygen consumption in the deep water and 10 percent or less in the lower (<400 m) thermocline region can be accounted for.

In press: Journal of Marine Research.

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THE INPUT OF ATMOSPHERIC $n\text{-C}_{10}$ TO
 $n\text{-C}_{30}$ ALKANES TO THE OCEAN

Robert A. Duce and Robert B. Gagosian

There are few data on organic compounds in the marine atmosphere. The only class for which any significant data base exists is the n -alkanes. Using available data on $n\text{-C}_{10}$ to $n\text{-C}_{30}$ alkanes in aerosols, rain, and in the gas phase from Atlantic, Pacific, and Indian Ocean regions, crude estimates of the deposition of n -alkanes to the world ocean are made. Deposition of gaseous and particulate n -alkanes by rain scavenging, of particulate n -alkanes by dry deposition, and of gaseous n -alkanes by direct vapor exchange with the ocean are evaluated. Rain scavenging of particulate n -alkanes appears to be the primary transport path to the ocean from the atmosphere. The total input of n -alkanes

to the ocean from the atmosphere is estimated to be from 0.03 to 0.3 Tg/yr. The accuracy of these estimates could be evaluated by the analysis of carefully collected rain samples over several oceanic regions. More precise estimates of the atmospheric input of organic material to the ocean will have to await more information of the inputs of the various organic compound classes to the sea surface and further understanding of the reaction products, pathways and rates of transformation of these compounds in the atmosphere.

In press: Journal of Geophysical Research.

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ENVIRONMENTAL IMPACTS

John W. Farrington

Organic geochemistry basic research needs in relation to environmental quality considerations are discussed within the context of organic geochemistry research applied to U. S. national energy needs. Specific recommendations are set forth in these critical research areas: factors controlling mobility and bioavailability, processes that concentrate pollutants, analytical chemistry, organic geochemical research to clarify key parts of the carbon cycle and how that cycle responds to increased CO₂ in the atmosphere. Immediate special emphasis on lacustrine, riverine and ground water systems is advocated because of the pending acceleration of exploitation of shale, heavy oil sands and coal.

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NO.2 FUEL OIL COMPOUNDS IN MYTILUS EDULIS: RETENTION AND RELEASE AFTER AN OIL SPILL

John W. Farrington, Alan C. Davis, Nelson M. Frew and Kathryn Rabin

Mytilus edulis contaminated by a brief two-day exposure to a slick from a No. 2 fuel oil spill in the Cape Cod Canal, Massachusetts, USA, were sampled six times during an 86-day post-spill period to study the rate of release of fuel oil compounds under field conditions. Detailed measure-

ments of compounds by high resolution glass capillary gas chromatography and quantitative glass capillary gas chromatography-mass spectrometry-computer systems analyses provided a more comprehensive examination of release rates based on compound type.

Biological half-lives were calculated for selected compounds for the first 21 days during which the release rate was exponential. Example half-lives are n-alkanes, 0.2-0.8 days; pristane, 1.5 days; C₂ (dimethyl or ethyl) naphthalenes, 0.9 days; methylphenanthrenes, 1.7 days. Changes in relative ratios of C₂ phenanthrenes during the release period were noted. The evidence available to date strongly supports the role of molecular weight and the accompanying property of water solubility as the main controlling factor in the rate of release of fuel oil compounds by *Mytilus*. However, the data for the rapid release of n-alkanes and C₂ phenanthrenes indicate molecular type and molecular configuration as additional key factors.

The data from this study are compared and contrasted to data from short term experimental studies in the laboratory, longer term studies from chronic exposure conditions, and data from two other oil spills with longer term exposure.

In press: Marine Biology.

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THE USE OF SEDIMENT TRAPS TO DETERMINE STEROL SOURCES IN COASTAL SEDIMENTS OFF PERU

R. B. Gagosian, J. K. Volkman and G. E. Nigrelli

Sterol distributions of particulate material, organisms and organism egestion products were compared to those of surface sediments to ascertain the sources of sterols in coastal Peruvian sediments. Free drifting sediment trap and seawater particulate matter analyses were undertaken to determine the distribution of sterols on large and small particles in seawater and their vertical flux to the sediments. Zooplankton fecal pellets, molts and carcasses and fecal pellets of anchoveta were analyzed for their potential contribution to the sedimentary sterols.

Zooplankton (copepods and euphausiids) molts and fecal pellets make significant contributions to some sedimentary sterols (cholesta-5-en-3 β -ol and cholesta-5, 22E-dien-3 β -ol). These sterols are also dominant in the sediment trap material.

Sedimentary sterols contain a strong phytoplankton source signal (24-methyl-cholesta-5,22E-dien-3 β -ol and 24-methyl-cholesta-5,24(28)-dien-3 β -ol). These diatom derived sterols appear to be delivered to the sediment quickly via sinking anchovy fecal pellets.

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VERTICAL TRANSPORT AND TRANSFORMATION OF BIOGENIC ORGANIC COMPOUNDS FROM A SEDIMENT TRAP EXPERIMENT OFF THE COAST OF PERU

Robert B. Gagosian, Gale E. Nigrelli and John K. Volkman

Sediment trap experiments using the lipid biomarker approach were undertaken in the Peru coastal upwelling region to answer three main questions concerning the sources, transport and transformation of organic matter in upwelling regimes. 1. How does the temporal and spatial variability of the vertical flux and composition of particulate matter vary as it sinks to the sediment surface? 2. What is the suitability of various lipids as biological source markers for sediments deeper in the sedimentary record? This involves a determination of how much of these compounds survive biological degradation in the water column and surface sediments. 3. What is the relationship between the organic matter composition of sinking particulate material and biological processes in the water column? The composition and vertical fluxes of the steroid class compounds are used as an example of how these questions may be answered.

In press: NATO Advanced Research Institute on Coastal Upwelling and Its Sediment Record, Plenum Press.

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VERTICAL TRANSPORT OF STEROID ALCOHOLS AND KETONES MEASURED IN A SEDIMENT TRAP EXPERIMENT IN THE EQUATORIAL ATLANTIC OCEAN

Robert B. Gagosian, Steven O. Smith and Gale E. Nigrelli

The vertical flux and free steroid alcohol (sterol) and ketone composition of particulate material was determined using

sediment traps deployed at 389, 988, 3755 and 5068 m at a station in the equatorial North Atlantic, PARFLUX E. Cholest-5-en-3 β -ol (cholesterol) was found to be the dominant sterol in all traps. This compound had a maximum flux at 988 m, accounting for more than 90 percent of the sterols at this depth. Inputs from mesopelagic zooplankton populations living in or migrating to depths between the 389 and 988 m traps appear to be responsible for this distribution. The deeper two traps exhibited an increased flux of phytosterols relative to cholesterol, probably due to (a) the incorporation of labile phytoplankton remains in fecal pellets and rapid transport into the deep sea and (b) differential dissolution of heterogeneous large particles. A maximum of 5-22 percent of the sterols produced in the euphotic zone were present in the 389 m trap. This value drops to less than 1 percent for the 5068 m trap, 200 m above the sediment surface.

In general steroid ketone fluxes gradually decreased with depth. Δ^4 -Stenones were found in greater abundance than their saturated counterparts. Cholest-4-en-3-one was the major steroid ketone detected in all the traps. A five-fold increase with depth in the cholest-4-en-3-one to cholesterol ratio is most likely due to microbial oxidation of sterols to steroid ketones, or higher Δ^4 -stenone inputs relative to sterols from organisms.

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VOLATILE ORGANIC COMPOUNDS AT A COASTAL SITE I. SEASONAL VARIATIONS

P. M. Gschwend, O. C. Zafiriou, R.F.C. Mantoura, R. P. Schwarzenbach and R. B. Gagosian

Alkylaromatics, alkanes, aldehydes, dimethylpolysulfides, and miscellaneous components were determined over a 15-month period at a coastal site. Alkylbenzenes appear dominated by anthropogenic inputs and air-sea exchange; in clean air, exchange is a major sink, with selective biodegradation showing minor effects in the summer. Offshore mixing and adsorption to sediments seems minor. Alkyl-naphthalenes showed a contrasting pattern, best explained in terms of a dominant wintertime source such as by space heating oil use.

Alkanes were frequently petroleum-derived, but pentadecane, heptadecane, and pristane showed evidence of strong biogenic sources as well. The aldehydes show complex behavior, with some evidence for auto-oxidative as well as plankton sources. The dimethylpolysulfides showed great variability; they may contribute significant sea-to-air sulfur fluxes if our measured levels are typical of the larger coastal region.

An incompletely identified octatriene occurs briefly in high concentrations; it seems likely to be an algal product related to the pheromone "fucoserraten", but the source species remains unknown.

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

A. Y. Huc, J. M. Hunt and J. K. Whelan

A thermal analysis-gas chromatography technique, previously described by Whelan et al. has been used to analyze cuttings from a Continental Offshore Stratigraphic Test (COST No. 1) drilled in the Gulf Coast of the USA. The data allowed an evaluation of the degree of maturation of the organic matter and provided an accurate determination of the depth of the threshold of intense oil generation at 3048 m (10,000 ft.). Qualitative changes of hydrocarbons in the C₇-C₁₄ range were determined by gas chromatography and confirmed by gas chromatography-mass spectroscopy. These data are discussed in terms of generation and migration processes. The catagenetic evolution results in a strong tendency for a proportional increase in n-alkanes. Mass transfer phenomena may be responsible for updip movement of the lighter hydrocarbons.

Published in: Journal of Geochemical Exploration, 15, 671-681.

THE ORIGIN OF PETROLEUM

John M. Hunt

Petroleum originates from the thermal alteration of organic matter buried in sedimentary rocks. Most oil forms in the 50 to 150°C, subsurface temperature interval with gas being formed somewhat

deeper. There is enough oil and gas remaining in the earth's crust to last for 100 years and possibly 200 years if the political and economic problems of drilling in less-developed countries can be solved.

Published in: Oceanus, 24, 2, 52-57, 1981.

PETROLEUM GEOCHEMISTRY OF THE ATLANTIC MARGIN

John M. Hunt

Vitrinitic type III gas-forming kerogen is the dominant type of organic matter in thermally mature sediments of the North Atlantic Margin from the Labrador Shelf to Florida based on studies to date. Mature liptinitic type II oil-forming kerogen is present in patches as in the Eastern Grand Banks area. This suggests that the dominant hydrocarbon production on the Atlantic Margin will continue to be gas and condensate with only modest quantities of oil being found.

Published in: AAPG: Short Course Notes entitled "Geology of Passive Continental Margins", AAPG Course Note Series 19.

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

THE VERTICAL FLUX OF PARTICULATE ORGANIC NITROGEN IN THE SEA: DECOMPOSITION OF AMINO ACIDS IN THE PERU UPWELLING AREA AND THE EQUATORIAL ATLANTIC

Cindy Lee and Carolyn Cronin

Marine particulate matter samples were collected in moored and free-drifting sediment traps deployed off the coast of Peru during February 1978. Three types of amino acids were analyzed in these samples: free extractable amino acids (FEA), hydrolyzed extractable amino acids (HEA) and total hydrolyzed amino acids (THA). FEA and HEA were also analyzed in moored trap samples from the PARFLUX E station in the equatorial Atlantic Ocean.

Amino acid fluxes from the two areas were related to primary productivity, POC flux and PON flux. In the Peru upwelling area, total amino acids account for 20-30 percent of the PIC flux and 40-65 percent of the PON flux. Relative decomposition rates were different for the three types of amino acids and may be higher at night than during the day. Individual amino acid concentrations indicated that diagenetic reactions may be occurring on the sinking particles. The rates, sites, and

mechanisms of these reactions are discussed as well as their implications for benthic metabolism.

Construction of a simple model from the Peru data indicates that about 80 percent of the amino acids produced during photosynthesis in the surface waters during primary production are decomposed above 14 m, assuming all amino acids were produced as POC. However, some proportion of the amino acids are produced or excreted as DOC and decomposed in the dissolved state. About 10 percent of the primary production is decomposed as particulate amino acids between 14 m and 50 m, and up to 12 percent may reach the sea floor.

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VOLATILE ORGANIC COMPOUNDS AT A COASTAL SITE II. SHORT-TERM VARIATIONS

R.F.C. Mantoura, P. M. Gschwend,
O. C. Zafiriou and K. R. Clarke

The concentrations of numerous volatile organic compounds (VOC) were monitored at a northeast coastal US site. Virtually all of the compounds showed similar levels of variability (relative standard deviations ~80 percent); much of this variation is attributable to short-term fluctuations rather than seasonal effects. Here we present two related examples, a "summer weekend effect" and a "winter weekend effect". The resultant systematic variations in alkylbenzene levels are explained by invoking a step-function change in the (anthropogenic) source function. The reaction of the system is dominated by the air-sea exchange process, which is quite rapid in shallow coastal waters.

A statistical analysis of the correlations among VOC concentrations in the more extensive winter survey revealed the presence of over 50 significant positive correlations. Cluster analysis revealed the existence of three significant subgroupings of covarying compounds (ten alkylbenzenes and total VOC, four saturated hydrocarbons, and three aldehydes). The significance of these groupings and their interpretation in terms of sources, sinks, and processes is discussed. We suggest that air-sea exchange may often dominate all other sinks for many volatile compounds; then, in appropriately simple environments, concentration measurements and appropriate

air-sea exchange data would permit estimation of in situ source functions.

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CAROTENOID TRANSFORMATION PRODUCTS IN THE UPWELLED WATERS OFF THE PERUVIAN COAST: SUSPENDED PARTICULATE MATTER, SEDIMENT TRAP MATERIAL, AND ZOOPLANKTON FECAL PELLET ANALYSES

D. J. Repeta and R. B. Gagosian

Carotenoids and their transformation products are measured in suspended particulate, sediment trap, and zooplankton fecal pellet samples collected in the Peruvian upwelling system. The carotenoid distribution of suspended particulate matter largely reflects the phytoplanktonic source of the material. However, both sediment trap and zooplankton fecal pellet samples contain significant amounts of carotenoid transformation products. These results are compared to an earlier experiment conducted in Buzzards Bay, Massachusetts, USA, to determine the time scales and mechanisms of the observed transformation reactions.

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CAROTENOID TRANSFORMATIONS IN COASTAL MARINE WATERS

D. J. Repeta and R. B. Gagosian

Rapidly sinking large particles contribute a major portion of the mass flux from marine surface waters to the sea floor. The recognition that organic matter associated with these particles undergoes major alterations in its chemical composition during vertical transit has raised new questions on the role of rapid transformation processes in carbon and nitrogen cycling, benthic nutrition, and post-depositional degradation. Analysis of specific organic compounds has established some of the compositional changes of these transformations. However, most of the changes observed represent the sum of biological production and degradation. For example, bacterial and chemical degradation of fatty acids in the water column may be completely masked by an even greater production of these compounds by

zooplankton. Hence it is often difficult to distinguish between competing degradative processes, and to assess the relative significance of each. Carotenoid pigments have characteristics which make them particularly suitable for use as organic tracers to distinguish between short term degradation processes. Carotenoids are widely distributed in both photosynthetic and nonphotosynthetic organisms; many of them are source specific; they contain diverse functional groups; and they represent one of the more labile biogenic compound classes in the sea. We report here for the first time the isolation and identification of carotenoid transformation products from sediment trap experiments conducted in coastal marine waters, and discuss the source and significance of observed transformation products with respect to a proposed degradation pathway.

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USE OF MICROBIAL ENRICHMENTS FOR THE STUDY OF THE ANAEROBIC DEGRADATION OF CHOLESTEROL

Craig D. Taylor, Steven O. Smith and Robert B. Gagosian

To demonstrate the potential of model microbial assemblages in studies of the biogeochemistry of complex organic molecules, anaerobic microbial populations capable of degrading cholesterol (cholest-5-en-3 β -ol) have been enriched from marine sediment sources. The bacterial enrichments actively mineralized the C-4 nucleus of the cholesterol ring system to carbon dioxide when nitrate was present as the terminal electron acceptor. Nitrite was found as an intermediate in the reduction of nitrate, indicating the presence of denitrifying bacteria in the enrichments. When sulfate was supplied as the sole electron acceptor, active dissimilation of cholesterol was not observed. In enrichments containing 5 mM nitrate, 95-98 percent of the added cholesterol was recovered as carbon dioxide (2-5 percent), transformation products (20-30 percent), or as the unmodified sterol (70-80 percent). Cholesterol transformation products thus far identified include 5 α - and 5 β -cholestan-3 β -ol, cholest-4-en-3-one, 5 α -androstan-3,17-dione and androst-4-en-3,17 dione.

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ACYCLIC ISOPRENOIDS AS BIOLOGICAL MARKERS

J. K. Volkman and J. R. Maxwell

Acyclic isoprenoids are those compounds based on the C₅ isoprene skeletal unit (2-methylbutadiene) formed from mevalonic acid via isopentenyl pyrophosphate and 3,3-dimethylallyl pyrophosphate (e.g., CONFORTH, 1959; NES and MCKEAN, 1977). Most naturally occurring isoprenoids have C₁₅ (e.g., farnesol), C₂₀ (e.g., phytol), C₃₀ (e.g., squalene) or C₄₀ (e.g., diphytanyl ethers) chain-lengths, although polyisoprenoids with up to 110 carbon atoms are known (MORTON, 1968). Phytol and phytol-derived isoprenoids are probably the most abundant in nature. In geological samples pseudo-homologous series of isoprenoids are found which are diagenetically related to C₅-based precursor biolipids. Although not strictly included in the term "acyclic isoprenoids", these compounds will be considered as such in this paper in common with other organic geochemistry literature.

Published in: Monograph on Biological Markers, Melbourne University Press.

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LIPID COMPOSITION OF COASTAL MARINE SEDIMENTS FROM THE PERU UPWELLING REGION

John K. Volkman, John W. Farrington, Robert B. Gagosian and Stuart G. Wakeham

The compositions of several lipid classes extracted from coastal sediments from the upwelling area at 15°S off Peru have been studied using capillary gas chromatography-mass spectrometry. Many of the sedimentary lipids originate from autochthonous sources in the water column as shown by comparison with the lipid composition of large particles trapped by free-drifting sediment traps deployed in the same area. A major mechanism by which many of these labile compounds reach the sea floor appears to be by incorporation into fast sinking anchoveta and zooplankton fecal pellets.

Detailed compositional data are presented for the hydrocarbon and acyclic ketone fractions. The hydrocarbons in the surface sediments show a predominance of branched acyclic C₂₅ polyunsaturated alkenes of presumed planktonic origin with smaller concentrations of long-chain

n-alkanes. The latter show little odd-predominance in offshore sediments in contrast to an inshore sediment where a high-plant contribution can be recognized. The ketone fractions contain significant amounts of very long-chain unsaturated C₃₇-C₃₉ ketones which may originate from the marine alga *Emiliania huxleyi*. These compounds are also abundant in the sediment trap particulates. Small amounts of C₂₃-C₃₅ n-alkane-2-ones are present in those sediments which contain n-alkanes of higher-plant origin but not in sediments further offshore. The data support earlier suggestions that these compounds may be indirect markers for terrigenous organic matter but sources in addition to in situ oxidation of n-alkanes are required to explain the distributions observed. The C₁₈ isoprenoid ketone 6,10,14-trimethylpentadecan-2-one is abundant in both surface and sub-surface sediments and presumably arises from degradation of phytol. Its concentration is also high in the sediment traps, implying a rapid formation in the water column.

In press: Advances in Organic Geochemistry.

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HIGH TEMPERATURE GLASS CAPILLARY GAS CHROMATOGRAPHY/MASS SPECTROMETRY OF WAX ESTERS, STERYL ESTERS AND TRIGLYCERIDES

S. G. Wakeham and N. M. Frew

Complex mixtures of wax esters, steryl esters and triglycerides isolated from representative biological and geochemical samples were analyzed using combined high resolution gas chromatography and electron impact and chemical ionization mass spectrometry. These low volatility neutral lipids containing up to 65 carbons were chromatographed intact on 15-20 meter high temperature (upper limit: 370°C) persilylated SE-52 glass capillary columns. Discrimination effects due to adsorptive losses and degradation were minimized using a non-vaporizing on-column injector and a direct all-glass capillary connection (380°C) to the quadrupole mass spectrometer. Structural information regarding the fatty acid and alcohol moieties was found to be maximal for methane-CI spectra in the case of wax and steryl esters, whereas EI spectra were most useful in interpreting triglyceride structures. Principal features of the EI and CI fragmentation patterns are discussed.

In press: Lipids.

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SOURCES AND FATES OF ORGANIC MATTER FROM A SEDIMENT TRAP EXPERIMENT IN THE EQUATORIAL NORTH ATLANTIC: WAX ESTERS, STERYL ESTERS, TRIGLYCERIDES, AND ALKYLDIACYLGLYCERYL ETHERS

Stuart G. Wakeham

The vertical flux and composition of wax esters, steryl esters, triglycerides, and alkyldiacylglycerols in particulate matter was determined in the equatorial Atlantic Ocean by deploying sediment traps at 389, 988, 3,755 and 5,068 m. Detailed compositional analyses of these biochemically important lipids were carried out by high temperature glass capillary gas chromatography and gas chromatography/mass spectrometry.

The distributions of these lipid compound classes in the sediment traps are discussed in terms of potential biological sources. Zooplankton fecal matter and intact zooplankters probably represent the most important input of these four compound classes to the shallower two traps, while the material in the deeper two traps appears to have been biogeochemically altered. The finding of these biochemically important compounds, often unsaturated, indicates that particle transit through the water column must be relatively fast.

Wax esters were most abundant in the 389 m sediment trap and decreased with increasing trap depth. Compounds ranging from C₂₈-C₄₄ were present at all depths. The major homologs were C₃₂, C₃₄, and C₃₆, most often mono-unsaturated. The dominant alcohol/acid combinations in the 389 m trap were C_{18:1}/C_{14:0} and C_{18:1}/C_{16:0}, but in the 988 m sample, C_{16:1}/C_{18:1} was the major wax ester. A flux maximum was observed for steryl esters at 988 m. Cholesteryl esters of C_{14:0}/C_{16:1} and C_{16:0}, and C_{18:1}/C_{18:0} fatty acids were the dominant steryl esters. For triglycerides, fluxes in the 389 and 988 m traps were similar, while the deeper pair of traps contained much less triglyceride. C₄₉, C₅₁, C₅₃ and C₅₅ compounds were the major triglycerides in all four sediment traps. Constituent fatty acids in the 389 m and 988 m samples were mainly C_{14:0}, C_{16:1}, C_{18:1}, C_{18:0}. In the 988 m material, C_{20:5}, C_{22:6} were also dominant. A homologous series of alkyldiacylglyceryl ethers was abundant in the 389 m trap material. The glyceryl ethers consisted of C₄₉-C₅₉ compounds composed of C_{16:0} ether moieties and

C14:0, C16:0, C18:1, C18:0 fatty acids.

In press: *Geochimica et Cosmochimica Acta*.

Supported by: ONR Contract N00014-79-C-0071.

VOLATILE C₁-C₈ COMPOUNDS IN MARINE SEDIMENTS

Jean K. Whelan

A review of the experimental method of headspace analysis for volatile compounds in sediments as currently used in this laboratory. Some typical results from recent sediments are presented.

In press: *Gas Chromatography/Mass Spectrometry Applications in Microbiology*, G. Odham, L. Larsson and P. A. Mardh, eds., Plenum Press.

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ANALYSIS OF ORGANIC PARTICULATES FROM BOSTON HARBOR BY THERMAL DISTILLATION-PYROLYSIS

Jean K. Whelan, Michael G. Fitzgerald and Martha Tarafa

The techniques of thermal distillation and pyrolysis coupled with gas chromatography (GC) and GC-mass spectrometry (GCMS) provide a "fingerprint" of the organic matrix of particulates collected from Boston Harbor. Pyrolysis products of particles caught in sediment traps closely resemble those of bottom sediments and are similar to those of some species of phytoplankton. GCMS analyses indicate that these organic matrices are all lipid rich, though the lipid in the seston appears to be distinct from that in both sediment-trap and phytoplankton samples. None of these samples resemble the sewage sludge dumped into the area, suggesting rapid reworking or remineralization of the sludge material.

In press: *Geochimica et Cosmochimica Acta*.

Supported by: NOAA Sea Grants 04-7-158-4414, 04-8-M01-149 and NA79AA-D-00102.

THE ORGANIC MATTER IN DSDP SITES 504 AND 505 SEDIMENTS STUDIED BY A THERMAL ANALYSIS - GAS CHROMATOGRAPHY TECHNIQUE

Jean K. Whelan and John M. Hunt

Sediments from DSDP sites 504 and 505 from the Costa Rica Rift were examined by gas chromatography-thermal distillation-pyrolysis. The Production Index, P.I., roughly reflected past thermal history for sediments containing similar types of organic matter as shown by pyrolysis-GC patterns. Highly burrowed sediments gave unreasonably high P.I. values as compared to unburrowed sections. A plot of organic carbon versus total pyrolyzed products suggests that sediments with less than one percent carbon are inert to hydrocarbon generation at these sites. It is postulated that the refractory organic material is caused by biological reworking rather than thermal processes.

In press: DSDP Initial Reports.

Supported by: NSF Grant OCE81-19508.

C₁-C₈ HYDROCARBONS IN IPOD LEG 64 SEDIMENTS: GULF OF CALIFORNIA

Jean K. Whelan and John M. Hunt

Sediments from the Baja California Continental Margin Transect - Sites 474 and 476 - showed small amounts of C₂-C₈ hydrocarbons and functionalized compounds (alkenes) typical of organic-rich recent cold (< 30°C) marine sediments. In contrast, some samples from sites 477, 478, 479 and 481A in the Guyamas Basin, an active spreading center, showed characteristics of thermally generated hydrocarbons. These include an increase (sometimes exponential) in amount and diversity of C₂-C₈ hydrocarbons and a decrease in alkenes in more thermally mature sediments. The results indicate that the formation of basaltic sills has minimal effect on C₂-C₈ hydrocarbon generation except in the immediate vicinity of the sill. The absence of light hydrocarbons close to the hottest sills suggests that the compounds distill away as they are formed in these areas of very active hydrothermal circulation. A sample of young sediment exposed to very high temperatures (> 300°C) from deeper thermal sources at the hottest of the sites, 477, showed a very limited hydrocarbon distribution including primarily ethane, benzene, and toluene together with smaller amounts of propane and butane.

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SEA WATER AND GEOCHEMISTRY

TRACE ELEMENT GEOCHEMISTRY OF DREDGED VOLCANIC ROCKS FROM THE GALAPAGOS SPREADING CENTER: ROLE OF CRYSTAL FRACTIONATION AND MANTLE HETEROGENEITY

David A. Clague, Frederick Frey,
Geoffrey Thompson and Susan Rindge

A wide range of rock types (abyssal tholeiite, Fe-Ti-basalt, andesite, and rhyodacite) were dredged from near 95°W and 85°W on the Galapagos Spreading Center. Computer modeling of major element compositions indicates that these rocks are derived from common parental magmas by successive degrees of fractional crystallization. However, the P_2O_5/K_2O ratios range from 0.83 (95°W) to 1.66 (85°W) implying distinct mantle source compositions for the two regions. These source regions also have distinct REE abundance patterns with $[La/Sm]_{EF} = 0.67$ at 95°W and 0.46 at 85°W. The sequence of fractionated magmas is also distinct in the two regions, with earlier fractionation of apatite and titanomagnetite in the lavas from 95°W. The mantle source regions for the two areas are both depleted in incompatible (and volatile?) elements, but the source region beneath 95°W is less severely depleted.

We have used incompatible trace element abundances in 26 samples to infer that the range of Fe-Ti basalts from 85°W represents 35 to 19 percent residual liquid following crystal fractionation of a mineral assemblage of plagioclase, clinopyroxene and lesser olivine. The most differentiated samples have also had small amounts of titanomagnetite removed. All the samples from 85°W can be related to a common parental magma that contains roughly 9 percent FeO^* , 1 percent TiO_2 , and has an Mg number of about 65. The samples from 95°W cannot all be derived from a common parental magma, and we infer that parental magmas derived by variable degrees of partial melting of a common source have reached the surface. The fractionation sequence consists of two parts -- the first leading to iron enrichment and the second leading to strong silica enrichment. We interpret the trace element data to indicate that the most iron-rich lavas represent about 32 percent residual liquid derived by crystal fractionation of plagioclase, clinopyroxene and lesser olivine from a parental magma with an Mg number of about 66. The silica enrichment trend reflects crystallization of titanomagnetite and some apatite as well.

Pigeonite, which is a minor fractionating phase in the major element models, cannot be separated from clinopyroxene fractionation using trace elements.

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CARBON-14 IN BANDED CORALS AND THE QUESTION OF ANTHROPOGENIC CO_2 IN THE OCEANS

Ellen M. Druffel

Carbon-14 was determined in aragonitic rings of known age of hermatypic corals. A depletion of ^{14}C during the years from about 1900 to 1952 was observed that was greater for corals from the Gulf Stream (-12‰) than for corals from the Peru Current (-6‰). A similar difference was observed in anthropogenic, mainly bomb-produced, ^{14}C during the years following 1952 in corals that grew in temperate regions, viz. Florida, Belize, Hawaiian Islands, as compared to corals from the Galapagos Islands, Fanning and Canton Islands, and Brazil, which are in tropical regions. The increase caused by anthropogenic ^{14}C amounted to 21.2 percent to 24.5 percent in temperate regions as compared to 10.0 percent to 15.0 percent in tropical regions. These results indicate that the ^{14}C in corals can be considered to be derived from two carbon reservoirs: 1) the atmosphere, and 2) the subsurface ocean. This can be seen from the linear relationship that exists between preanthropogenic $\Delta^{14}C$ and the Suess effect in the individual corals. A similar linear relationship exists between the preanthropogenic $\Delta^{14}C$ values and the maximum values of anthropogenic bomb ^{14}C as observed around 1973. As to be expected, the ^{14}C in the atmosphere at a given time is independent of geographic location. It is, however, somewhat surprising that the subsurface carbon dioxide reservoir shows the same $\Delta^{14}C$ value, viz. the same radiocarbon age, independent of location. It appears now that the apparent ^{14}C age of the surface waters of the ocean during preanthropogenic times was approximately 400 years or older and the upwelling waters from subsurface depths have an apparent age of 750 years, corresponding to a $\Delta^{14}C$ of about -90‰. Bomb carbon-14 measurements indicate that from the change of $\Delta^{14}C$ in the surface ocean in post-bomb times, the rate of input of anthropogenic ^{14}C can be calculated. From this quantity and from the undisturbed preanthropogenic $\Delta^{14}C$ values at each location, vertical mixing rates can be calculated. In the mixed

layer where the corals grew it appears that there is an upward replacement rate of 7 m/yr in the western North Atlantic and 22 m/yr in the eastern tropical Pacific. This is considerably slower than current estimates of these quantities given in the literature.

Published in: Proceedings of the Conference on Analysis and Interpretation of Atmospheric CO₂ Data, Bern, September 14-18, 1981, 201-208.

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BANDED CORALS: CHANGES IN OCEANIC CARBON-14 LEVELS DURING THE LITTLE ICE AGE

Ellen M. Druffel

Radiocarbon analyses and stable isotope measurements are presented for two recent cores of banded corals from the Florida Straits. These values provide a record of ¹⁴C/C variations in inorganic carbon in the surface waters of the Gulf Stream from A.D. 1642 to 1800. A rise in $\Delta^{14}\text{C}$ of 70‰ was noticed for coral growth during the early 1700's. It is shown that this rise was most likely induced by an increase in $\Delta^{14}\text{C}$ of 200‰ that occurred initially in atmospheric CO₂ around A.D. 1700. Oxygen-18/oxygen-16 ratios of these coral bands show a small decrease of water temperature (~1°C) during the latter part of the Little Ice Age (A. D. 1700-1725). These results indicate that the rise of atmospheric ¹⁴C at A.D. 1700, and possibly the temperature change as well, was caused by a decrease in solar activity (Maunder minimum).

In press: Science.

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ON THE RADIOCARBON RECORD IN BANDED CORALS: EXCHANGE PARAMETERS AND NET TRANSPORT OF ¹⁴CO₂ BETWEEN ATMOSPHERE AND SURFACE OCEAN

E. M. Druffel and H. E. Suess

Interpretation is presented of radiocarbon measurements reported previously for annual rings of massive corals. These measurements represent the ¹⁴C/C ratios in dissolved inorganic carbon (DIOC) in the surface ocean waters of the Gulf Stream and the Peru Current at the time of coral ring formation. A depletion in radiocarbon concentration was observed in coral rings that had grown

during the years A.D. 1900 to 1952. It was caused by dilution of existing ¹⁴C levels with dead CO₂ from fossil fuel burning (the Suess effect, or S_e). The observed depletion of radiocarbon was greater in corals from the Gulf Stream (-110‰ than in corals from the Peru Current (-60‰). A similar trend was observed in the distribution of bomb-produced ¹⁴C in corals that had grown during the years following A. D. 1952. The concentration of bomb-produced radiocarbon was much higher in corals from temperate regions (Florida, Belize, Hawaiian Islands) than in corals from tropical regions (Galapagos Islands and Canton Island). These data are used to calculate exchange parameters for ¹⁴CO₂ between atmosphere and ocean. A linear relationship exists between preanthropogenic $\Delta^{14}\text{C}$ values and the S_e values for individual corals. This relationship indicates that the ¹⁴C in corals can be considered from two carbon reservoirs: (i) the atmosphere and (ii) the subsurface ocean. A similar linear relationship between the preanthropogenic $\Delta^{14}\text{C}$ values and the concentration of bomb-produced ¹⁴C is observed for the individual corals during A. D. 1973. Analyses of these linear relationships reveal that the apparent radiocarbon age of the surface waters of the ocean during the preanthropogenic period ranged from about 300 to 520 years B.P., while the upwelling waters from subsurface depths had an apparent age of 670 years B.P., corresponding to a $\Delta^{14}\text{C}$ of -860‰. From the change of $\Delta^{14}\text{C}$ noticed in the surface ocean during post-bomb times, an approximate rate of net input of ¹⁴CO₂ to the ocean waters is calculated to be .080‰/yr/0‰ difference between atmosphere and ocean. From this input and from preanthropogenic $\Delta^{14}\text{C}$ values found at each location, vertical mixing rates in the area of the Peru Current are estimated to be at least three times greater than those in the Gulf Stream System.

In press: Journal of Geophysical Research.

Supported by: NSF Grants EAR78-15183 and OCE79-17653.

TIME HISTORY OF TRACE ELEMENTS IN SEDIMENTS FROM STANDLEY LAKE, COLORADO

Merrill Heit, Catherine S. Klusek, Herbert L. Volchok and John C. Burke

Eighteen trace elements were analyzed in sections from a 50 cm-long sediment core from Standley Lake, Colorado. The core was dated by the use of bomb-produced ¹³⁷Cs. Ten of the elements measured (Ag, Cd, Cu, Ga, Hg, Pb, Se, Sn, Tl and Zn) appear to be

enriched in this sediment; seven (Al, As, Be, Co, Cr, Ni, and V) are probably of local geological origin; and Te was not detected. Several of the constituents increase with depth in the sediment, and the concentrations of some compare to levels in lake sediments near highly industrialized centers. Based upon comparisons with other work, fluxes, enrichment factors (benzo(a)-pyrene concentrations, and other evidence we conclude that the primary source of the "excess" elemental concentrations is local stream pollution.

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International, 4, 229-237, 1980.

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THE ORIGIN OF TRACE ELEMENTS AND
POLYCYCLIC AROMATIC HYDROCARBONS
IN SEDIMENT CORES
FROM TWO LAKES IN THE ADIRONDACK
ACID RAIN REGION

Merrill Heit, Yulin Tan,
Catherine S. Klusek and John C. Burke

The origins of trace elements and polycyclic aromatic hydrocarbons (PAHs) in two remote lakes in New York State's Adirondack acid rain region are discussed in relation to combustion, biogenesis, long distance atmospheric transport from industrial areas and inputs from local anthropogenic sources. The prime source of most of the 3-7 ring PAHs and trace elements measured is ascribed to anthropogenic combustion.

Published in: Water, Air, Soil
Pollution, Volume 15.

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DE-AC-02-76-EV-03563, A006.

DEEP ADVECTIVE TRANSPORT OF LITHOGENIC
PARTICLES IN PANAMA BASIN

Susumu Honjo, Derek W. Spencer
and John W. Farrington

Sediment traps were deployed at several depths (660 to 3800 m) in the Panama Basin. The flux of lithogenic particles increased with increasing depth. This increase comprised, primarily, beidellite particles (a smectite clay) which were identical to the clay occurring in bottom sediment on the continental slope to the west of the sediment trap mooring. Beidellite vertical flux at the Panama Basin station increased when an easterly current prevailed, and decreased when the

current reversed, indicating that a major portion of smectite was transported horizontally at mid-water depth to the mooring site from the nearby continental slope.

In press: Science.

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0262, NR 083-009 and N00014-74-C-
0262, NR 083-004.

A GEOCHEMICAL STUDY OF ROCKS FROM THE
WALVIS RIDGE, SOUTH ATLANTIC

Susan E. Humphris and Geoffrey Thompson

Basalts from the Walvis Ridge, an aseismic ridge in the eastern South Atlantic Ocean, have been analysed to investigate the origin and evolution of this feature, and its relation to Tristan da Cunha. The principal minerals in the basalts are plagioclase, clinopyroxene and iron oxides. The alkali nature of the samples is indicated by the high content of the orthoclase end member in the feldspars, and the aluminous titanite, which contain up to 3.2 wt percent TiO_2 . Chemically, the basalts can be divided into two related major groups. Group I is slightly more evolved and is characterized by high TiO_2 , FeO^* , V and Zr concentrations, while Group II contains relatively low TiO_2 and FeO^* contents, but has high concentrations of CaO , Na_2O and Al_2O_3 . The differences between them are explained by the relative importance of ilmenite precipitation in Group I and plagioclase precipitation in Group II.

All of the basalts from the Walvis Ridge are geochemically distinct from Mid-Ocean Ridge basalts originating at spreading centers including those at equivalent latitudes in the South Atlantic. A change in the Zr/Nb ratio of the basalts is observed along the Walvis Ridge, from a value of ten at the eastern end, six in the central section, to about four for Tristan da Cunha. This suggests that the composition of the mantle source was different for the various provinces along the Ridge and may have changed progressively with time if the Walvis Ridge represents the trace of the Tristan da Cunha hot spot.

In press: Chemical Geology.

Supported by: NSF Grants OCE74-22971
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ON THE CLIMATE OF A SUBTROPICAL OCEAN GYRE: DECADE TIMESCALE VARIATIONS IN WATER MASS RENEWAL IN THE SARGASSO SEA

William J. Jenkins

A simple concept model of the climatology of a subtropical ocean gyre is developed on the basis of assumed isopycnal transport and latent heat flux. The 27 year record of annually averaged salinities on isopycnals near Bermuda shows clear and systematic variations, and significant (>95 percent confidence) correlations with oxygen (positive) and vertical density gradient (negative) support the hypothesis. ^3He variations at two time periods are also consistent. Comparison with the Marsden Square 115 heat flux record shows moderately good lag correlations with increasing lag with depth. The seasonal records show the post winter arrival at the station of renewed water. Back calculation of renewal rates based on oxygen, salinity and ^3H - ^3He data shows a factor of two variations in shallow water mass renewal rates over the past three decades.

Published in: Journal of Marine Research.

Supported by: NSF Grant OCE79-19815.

FINE-SCALE ISOTOPIC HETEROGENEITY IN THE SUB-ATLANTIC MANTLE

N. Machado, J. N. Ludden,
C. Brooks and G. Thompson

The Sr and Nd isotopic compositions of basaltic glasses from the Kane Fracture Zone (22°-24°N in the Atlantic Ocean) are reported. These glasses represent the most depleted basaltic magma yet encountered and reveal mantle heterogeneity of a scale of tens of kilometers. The observations have implications for the dynamics of mantle melt segregation and the role of a major transform in mantle convection.

In press: Nature.

Supported by: NSF Grant OCE77-26842.

MULTICOMPONENT ELECTROLYTE DIFFUSION CORRECTIONS FOR NORTH ATLANTIC SEDIMENT

P. C. Mangelsdorf and F. L. Sayles

Lasaga's (1979) ion-pairing model for ion-ion interactions in multi-component diffusion in sediments is applied to in situ concentration data for North Atlantic sediments. The model is modified slightly to permit separate fluxes of total CO_2

and of carbonate alkalinity, and to permit gradients of pH and alkalinity to be included. The dominant effects are the enhanced diffusion coefficients ascribed by the Lasaga model, and our own cation readjustment to eliminate the apparent Cl^- flux. In all cases, the calculated fluxes correlate very well with those calculated ignoring all interaction, so that no qualitative differences in interpretation are required by the inclusion of ion-ion interactions.

In press: American Journal of Science.

Supported by: NSF Grant OCE78-24685.

METABASALTS, AXIAL HOT SPRINGS, AND THE STRUCTURE OF HYDROTHERMAL SYSTEMS AT MID-OCEAN RIDGES

Michael J. Mottl

Knowledge of the chemical transfer and mineralogical transformations which occur when seawater reacts with basalt at elevated temperatures and pressures can be used along with geological and geophysical data to deduce the typical structure and evolutionary sequence for hydrothermal systems within the oceanic crust along the axis of a mid-ocean ridge. Studies of metabasalt and metadiabase dredged from fault scarps along the axial valley of the Mid-Atlantic Ridge reveal consistent relationships among the bulk chemistry of the altered rocks and their secondary mineralogy, mineral abundances, and mineral compositions, especially for chlorite. These relationships can be interpreted in terms of the distribution of alteration with respect to time, temperature, and water/rock ratio in young crust. Within the temperature range of the greenschist facies (~250-450°C) assemblages of chl-ab-ep-act, chl-ab-ep-act-qtz, chl-ab-qtz, and chl-qtz are produced at successively higher effective seawater to rock ratios. Toward higher ratios chlorites tend to become more Mg-rich. Pillow basalts of layer 2 are commonly altered under these conditions by seawater which is on the descending, rather than the ascending, limb of a convection system; this type of alteration, which reflects moderately high water/rock ratios, may characteristically occur above a still partially molten magma chamber. As the magma chamber solidifies and is then penetrated, more pervasive alteration of the deeper part of layer 2 and of layer 3 occurs at lower water/rock ratios, producing solutions such as those recovered from springs on the Galapagos Rift and the East Pacific Rise at 21°N. Localized upwelling limbs of the convection system

can produce veins filled with quartz, sulfides, and Fe-rich chlorite.

In press: Bulletin of the Geological Society of America.

Supported by: NSF Grants OCE78-19455 and OCE77-26842.

CHEMISTRY OF WATERS SAMPLED FROM BASALTIC BASEMENT AT SITES 501, 504 AND 505

Michael J. Mottl, Roger N. Anderson,
William J. Jenkins and James R. Lawrence

Two methods were used in the first attempts to sample formation waters from basaltic basement in the oceanic crust. In the first, water occupying the hole was sampled some time after pumping had stopped. In the second, water from both the hole and the surrounding rocks was sampled by sealing off a 3-m section at the bottom of the hole and opening a large-volume sampler, thereby creating a negative pressure. Neither method produced a sample containing an appreciable and unambiguous component of true formation water, although the samples generally showed large compositional differences from seawater. Samples from Holes 505B and 501 were mainly mixtures of surface seawater used as drilling fluid and pore water from sediment which fell down the hole. Samples from Hole 504B contained a large fraction of seawater which displayed large chemical changes due to reaction with basement basalts. Tritium analyses revealed the samples to be surface seawater pumped into the formation a few days earlier which had reacted rapidly with basalt at the in situ temperature of 80°C. The solutions had gained Ca and lost Mg on a mole-for-mole basis, lost K, and gained Si. These results are consistent with those of laboratory experiments reacting seawater with basalt, and indicate that in situ reaction rates in the crust are sufficiently rapid to produce large changes in solution chemistry almost instantaneously at 80°C. The absence of an ^{18}O shift in the solutions indicates that the amount of rock which reacted with the solution during its brief residence in the crust was negligible.

In press: DSDP Initial Reports.

Supported by: NSF Grant OCE80-19056.

ADVECTION OF PORE FLUIDS THROUGH SEDIMENTS IN THE EQUATORIAL EAST PACIFIC

Frederick L. Sayles

Measurements of $^4\text{He}/^3\text{He}$ and Ca^{2+} in the pore waters of sediments at two locations in the Eastern Equatorial Pacific indicate that solution advection is occurring through the sediments. Both $^4\text{He}/^3\text{He}$ and Ca^{2+} yield velocity values for advective flow of about 20 cm/yr. Mass balance constraints are also consistent with the interpretation presented. Flow appears to be occurring through relatively thick sediments - on the order of 300 m.

In press: Science.

Supported by: NSF Grants OCE80-24685 and OCE79-19023.

TRISTAN DA CUNHA HOTSPOT

J. G. Schilling, S. E. Humphris and
G. Thompson

We report first geochemical results on basalts dredged on the crest over MAR from 47°S to 31°S with R/V ATLANTIS II. Location of the MAR crest is ill-defined and the rift poorly developed, particularly over the Tristan-Gough platform where the axis is elevated. La/Sm variation along this profile ranges from 0.64 to 1.44. Two noticeable La/Sm anomaly highs were found at the latitude of Tristan and Gough spreading flow lines, despite that the MAR is 400 km away from these two hotspots. These geochemical anomalies are also seen in other incompatible element abundances, e.g., Ti, K, Ba and Nb. This may suggest that narrow mantle flow channels have persisted for 25 m.yrs. at these two latitudes, as the MAR drifted westward from these two hotspots. Alternative models will also be considered. These first results are part of a long-term URI/WHOI cooperative program on the petrology and geochemistry of the South Atlantic seafloor and its relationship to South Atlantic islands.

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62, 424, 1981.

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TRACE ELEMENT ANALYSES OF POWDERED,
SMALL (100 mg) ROCK AND MINERAL SAMPLES
BY X-RAY FLUORESCENCE ANALYSIS

B. Schroeder, G. Thompson
and M. Sulanowski

An automatic computer controlled Philips wavelength-dispersive x-ray spectrometer is used to analyse a variety of rocks and minerals for their trace element contents. For many samples only restricted amounts of sample are available. We have developed a technique for analyzing 100 mg amounts of powdered sample. This technique involves a slurry type sample dispersion and reproducible deposition of the powder onto a special filter. The sample is then sealed in position and analyzed. For those trace elements with high energy fluorescent spectra (K lines), e.g., Sr, Ba, Zr, Nb, Rb and Y, the sample can be treated as a 'thin layer' and absorption or enhancement effects are negligible. For lower energy spectra, e.g., V, Cr, Co, Ni, Cu and Zn, absorption effects are noticeable and must be corrected. Precision and accuracy are of the order of ± 5 percent and make the technique a very valuable addition to the analytical chemist's arsenal.

In press: American Laboratory.

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HYDROTHERMAL ALTERATION OF BASALT
BY SEAWATER
UNDER SEAWATER-DOMINATED CONDITIONS

William E. Seyfried, Jr.
and Michael J. Mottl

Fresh mid-ocean ridge basalt glass and diabase have been reacted with seawater at 150–300°C, 500 bar, and water/rock mass ratios of 50, 62, and 125, using experimental apparatus which allowed on-line sampling of solution to monitor reaction progress. These experiments characterize reactions under what we have called "seawater-dominated" conditions of hydrothermal alteration, which produce a distinctly different solution chemistry and secondary mineral assemblage from that produced at lower water/rock ratios under "rock-dominated" conditions.

In an experiment at 300°C, basalt glass undergoing alteration removed nearly all Mg^{2+} from an amount of seawater 50 times its own mass. In the process, the glass was converted entirely to mixed-layer smectite-chlorite, anhydrite, and minor hematite. Removal of Mg from seawater occurred as a $Mg(OH)_2$ component

incorporated into the secondary clay. This produces a precipitous drop in solution pH early in the experiment, accompanied by a dramatic increase in the concentrations of Fe, Mn and Zn in solution. As Mg removal neared completion and the glass was hydrolyzed, pH rose again and heavy metal concentrations dropped. This experiment at a water/rock ratio of 50 is transitional in that it exhibits the near-neutral pH and low Mg and heavy metal concentrations characteristic of solutions produced under rock-dominated conditions, while at the same time it produced the simple mineral assemblage, consisting mainly of secondary Mg-Al-silicates, characteristic of reactions under seawater-dominated conditions.

At water/rock ratios of 62 and 125 and 150–300°C, both solutions and solids reflected reaction under seawater-dominated conditions. The mineral assemblage produced was similar to that at a water/rock ratio of 50, $\pm$ quartz, but some Mg by necessity remained in solution, causing the pH to remain highly acid for the duration of the experiments and resulting in significant steady-state concentrations of Fe, Mn and Zn in solution. At 300°C nearly all of the Na, Ca, Cu, Zn and CO_2 and most of the K, Ba, Sr and Mn were leached from the silicates. H_2S , Al, Si and possibly Co were also significantly mobilized, whereas V, Cr and Ni were not. Little or no seawater sulfate was reduced, possibly due to sluggish kinetics of Fe^{2+} oxidation at low pH, and the concentration of H_2S was greatly exceeded by that of iron.

All of the solutions were greatly super-saturated with quartz, although quartz was detected in only one experiment, at 300°C and $w/r = 125$. All of the solutions were close to saturation with anhydrite, which appears to be stable with respect to pyrite. The solutions were generally undersaturated with Mg-hydroxysulfate.

Although submarine hot spring solutions sampled to date along mid-ocean ridges clearly come from rock-dominated hydrothermal systems, evidence from ocean floor metabasalts and from heat flow studies indicates that seawater-dominated conditions of alteration prevail at least locally both in axial high-temperature systems and in ridge flank systems at lower temperatures.

In press: *Geochimica et Cosmochimica Acta*.

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PETROLOGY AND GEOCHEMISTRY OF BASALTIC
ROCKS FROM RIO GRANDE RISE, SOUTH
ATLANTIC: DEEP SEA DRILLING
PROJECT LEG 72, HOLE 516F

G. Thompson, S. E. Humphris
and J. G. Schilling

Basalts from hole 516F, DSDP Leg 72 on the Rio Grande Rise are tholeiitic in character but differ from normal mid-ocean ridge basalts in the South Atlantic in higher concentrations of incompatible elements such as Ti, K, V, Sr, Ba, Zr, Nb, LREE and lower concentration of Mg, Cr and Ni. They contrast with previously reported basalts from the Rio Grande Rise which were highly alkalic in character. The Rio Grande Rise basalts from hole 516 (age 83 m. yrs.) are generally similar to basalts from the eastern end of the Walvis Ridge (80-100 m. yrs.). It is suggested that they either originated, like the Walvis Ridge, from a mantle hot spot that is different from the present day hot spot (Tristan da Cunha) and which has changed composition with time, or from a spreading center that was shallow and chemically influenced by the adjacent hot spot, similar to the present day Mid-Atlantic Ridge near the Azores and near Tristan da Cunha.

In press: DSDP Initial Reports, 72.

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A SELF-POWERED PUMPING SYSTEM FOR
IN SITU EXTRACTION OF PARTICULATE
AND DISSOLVED MATERIALS FROM LARGE
VOLUMES OF SEAWATER

C. L. Winget, J. C. Burke,
D. L. Schneider and D. R. Mann

A pumping system has been developed for the in situ extraction of particles and of dissolved constituents from large volumes of seawater. The assembly consists of a battery-powered submersible pump, filters and chemisorptive cartridges; it is entirely self-contained and has been used successfully on ship's hydrographic wire to depths as great as 5800 m. The pump is designed to operate at a maximum pressure drop of 66 cm of Hg; flow rates have varied from 1.3 to 5.1 l/min. We have sampled volumes as large as 758 l, and the measured battery drain suggests that volumes several times this could be pumped at any depth. The system is being used to study a variety of artificial radionuclides, but modifications of the filter or chemisorbent units would make it useful in many other geochemical applications.

In press: Journal of Marine
Research.

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DE-AC02-81-EV-10694.

RADIOCHEMISTRY

CONCENTRATION, VERTICAL FLUX,
AND REMINERALIZATION OF PARTICULATE
URANIUM IN SEAWATER

Robert F. Anderson

Concentrations and fluxes of particulate uranium have been measured throughout the water column at several locations in the Atlantic and Pacific Oceans with in situ filtration systems and sediment traps. Dissolved uranium is fixed to particles in surface seawater. Organic matter appears to be the carrier phase. Formation of particulate authigenic uranium below the surface waters could not be detected. Authigenic uranium is remineralized within the bathypelagic layers at the open ocean sites studied. In the Panama Basin, an upwelling area with high biological productivity, remineralization of authigenic uranium in the deep water column was not observed. The rate of remineralization of authigenic uranium in the deep sea is insufficient to produce a measurable uranium concentration gradient between surface and deep waters within the mixing time of the oceans. Formation of authigenic uranium in the water column in areas such as the Panama Basin is not a significant sink for uranium on an ocean wide basis.

In press: Geochimica et
Cosmochimica Acta.

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DETERMINATION OF NATURAL ACTINIDES
AND PLUTONIUM IN MARINE
PARTICULATE MATERIAL

R. F. Anderson and A. P. Fleer

The natural actinides ^{227}Ac , ^{228}Th , ^{230}Th , ^{232}Th , ^{234}Th , ^{231}Pa , ^{238}U and ^{234}U and the alpha emitting plutonium isotopes are determined in samples of suspended marine particulate material and sediments. Analysis involves total dissolution of the samples to allow equilibration of the natural isotopes with added isotope yield monitors followed by

coprecipitation of hydrolyzable metals at pH 7 with natural Fe and Al acting as carriers to remove alkali and alkaline earth metals. Final purification is by ion exchange chromatography (Dowex AG 1-X8) and solvent extraction for Pa. The method has been successfully interfaced with published methods to include the determination of ^{55}Fe , ^{137}Cs , ^{90}Sr and ^{241}Am on the same samples.

In press: Analytical Chemistry.

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ELEVATED CONCENTRATIONS OF ACTINIDES IN MONO LAKE

R. F. Anderson, M. P. Bacon
and P. G. Brewer

Thorium, Pa, U and Pu (IV, V, VI and uncertain oxidation states, respectively) are all present at much higher concentrations in Mono Lake, a saline, alkaline lake in eastern central California, than in seawater. Low Ac/Pa and Am/Pu ratios indicate that the concentrations of trivalent actinides are not similarly enhanced. The elevated concentrations of the ordinarily very insoluble actinides are maintained by natural ligands in solution, which inhibit their chemical removal from the water column, rather than by an unusually large rate of supply.

In press: Science.

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ACCUMULATION RATES OF TH-230, PA-231 AND SOME TRANSITION METALS ON THE BERMUDA RISE

M. P. Bacon and John N. Rosholt

Measurements of ^{238}U , ^{234}U , ^{230}Th , ^{232}Th , ^{231}Pa , Mn, Fe, Co, Ni, Cu and Zn were made on 23 samples from core GPC-5, a 29-m giant piston core from a water depth of 4583 m on the northeastern Bermuda Rise ($33^{\circ}41.2'\text{N}$, $57^{\circ}36.9'\text{W}$). This area is characterized by rapid deposition of sediment transported by abyssal currents. Unsupported ^{230}Th and ^{231}Pa are present throughout the core but, because of large variations in the sedimentation rate, show marked departures from exponential decay with depth. The trend with depth of the $^{231}\text{Pa}_{\text{ex}}/^{230}\text{Th}_{\text{ex}}$ ratio is consistent with the average accumulation rate of 36 cm/1000 y reported earlier on the basis

of radiocarbon dating and CaCO_3 stratigraphy. When expressed on a carbonate-free basis, concentrations of Mn, Co, Ni, Cu, Zn, $^{230}\text{Th}_{\text{ex}}$ and $^{231}\text{Pa}_{\text{ex}}$ all show cyclic variations positively correlated with those of CaCO_3 . The correlations can be explained by a model in which all of these constituents, including CaCO_3 , are supplied to the sediments from the water column at a constant rate. Concentration variations are controlled by varying inputs of terrigenous detritus, with low inputs occurring during interglacials and high inputs during glacials. Relationships between the metal and $^{230}\text{Th}_{\text{ex}}$ concentrations permit estimates of the rates at which the metals are removed to the sediment by scavenging from the water column. The results, in $\mu\text{g}/\text{cm}^2\text{-1000 y}$, are: 4300 ± 1100 for Mn, 46 ± 16 for Ni and 76 ± 26 for Cu. These rates are somewhat larger than ocean-wide averages estimated by other methods, and the absolute rate of ^{230}Th accumulation in GPC-5 averages about nine times higher than production in the overlying water column. This part of the Bermuda Rise and similar bottom-current deposits may act as important accumulators of elements scavenged from seawater.

In press: Geochimica et Cosmochimica Acta.

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DISTRIBUTION OF THORIUM ISOTOPES BETWEEN DISSOLVED AND PARTICULATE FORMS IN THE DEEP SEA

M. P. Bacon and R. F. Anderson

The distribution of ^{234}Th , ^{230}Th , and ^{228}Th between dissolved and particulate forms was determined in seventeen seawater samples from the Guatemala and Panama Basins. Sampling was carried out *in situ* with battery-powered, submersible pumping systems in which the seawater first passed through a Nuclepore filter ($1.0 \mu\text{m}$ pore size) and then through a cartridge packed with Nitex netting that was impregnated with MnO_2 to scavenge the dissolved Th isotopes. Natural ^{234}Th was used as the tracer for monitoring the efficiency of scavenging. For all three isotopes most of the activity was found in the dissolved form. On the average 4 percent of the ^{234}Th , 15 percent of the ^{228}Th , and 17 percent of the ^{230}Th occurred in the particulate form, though the percentages were found to be strongly dependent on particle concentration. These distributions are not consistent with

chemical scavenging models that assume irreversible uptake of Th on particle surfaces. The results can be explained, however, if continuous exchange of Th isotopes between seawater and the particle surfaces is assumed. Vertical profiles of both particulate and dissolved ^{230}Th show increasing concentrations with depth, as required by the assumption of reversible exchange. Some of the dissolved ^{230}Th profiles, however, show a reversal of this trend near the bottom, indicating accelerated scavenging near the water/sediment interface. Kinetics of both adsorption and desorption can be examined if at least two Th isotopes are measured in the same samples. Results show that reaction times are short (a few months) compared to the residence time of suspended matter in the deep ocean (several years), indicating that particles suspended in the deep sea are close to equilibrium with respect to exchange of metals at their surfaces.

In press: Journal of Geophysical Research.

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THORIUM ISOTOPE DISTRIBUTIONS IN THE EASTERN EQUATORIAL PACIFIC

M. P. Bacon and R. F. Anderson

Measurements of the radiogenic Th isotopes ^{234}Th , ^{230}Th and ^{228}Th in seawater show that all of the isotopes occur mainly in the dissolved form ($< 1.0 \mu\text{m}$). The fraction of the Th found in the particulate form increases as the radioactive half-life of the isotope increases. From our interpretation of the data we conclude that chemical scavenging of Th in the deep sea occurs by a reversible exchange process and that the rate of exchange is fast compared with the rate of removal of the particulate matter. As a result the suspended particles are nearly equilibrated with the surrounding water with respect to exchange of Th isotopes at their surfaces. This suggests that chemical equilibrium principles may be applicable to the problem of trace-metal scavenging in the deep sea.

In press: Conference Proceedings of NATO Advanced Research Institute.

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URANIUM RESULTS FROM HOLE 504B WATER SAMPLES

Michael P. Bacon

Measurements of U concentration and $\text{U}/^{238}\text{U}$ ratio were made in five of the drill hole samples. The results indicate that loss of U had occurred either during sampling or during storage of the samples, probably as a result of adsorption by rust particles on the walls of the sampling system. Within analytical uncertainty, $^{234}\text{U}/^{238}\text{U}$ ratios in the samples were identical to those in unreacted seawater. Thus it is not possible to detect any U exchange that may have occurred during reaction of the solutions with the basement formation. Improvement in sampling technique is a necessity for future studies of U and probably other trace elements in drill hole water samples.

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ALKALI AND Sr ISOTOPE GEOCHEMISTRY OF WATERS COLLECTED FROM BASALTIC BASEMENT, HOLE 504B

Stanley R. Hart and Michael J. Mottl

Basalt formation waters collected from sub-basement depths of 195, 201, 365 and 440 meters, hole 504B, show inverse linear relationships between $^{87}\text{Sr}/^{86}\text{Sr}$ and Ca, $^{87}\text{Sr}/^{86}\text{Sr}$ and Sr, and between K and Ca. Based on an assumed Ca content of 1340 ppm for a fully reacted formation water end-member, the K, Sr and $^{87}\text{Sr}/^{86}\text{Sr}$ values for the end-member are 334 ppm, 7.67 ppm, and 0.70836 respectively. With respect to contemporary seawater at site 504B, K is depleted by 13 percent, Sr is enriched by 2.7 percent, and $^{87}\text{Sr}/^{86}\text{Sr}$ is depleted by 0.8 percent. The Sr/Ca ratio of the formation water (.0057) is much lower than that of seawater (.018), but is similar to the submarine hot spring waters from the Galapagos rift and 21°N, and to geothermal brines from Iceland. At the intermediate temperatures represented by the 504B formation waters (70° - 105°C), the interaction between seawater and the oceanic crust produces large solution enrichments in Ca, the addition of a significant basalt Sr isotope component accompanied by only a minor elemental Sr component, and removal from solution of seawater K, Rb, Cs and Ba contents of the formation waters appear to be perturbed by contamination, possibly from drilling muds.

In press: DSDP Initial Reports.

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and OCE80-19056.

RADIOACTIVE TRACERS IN THE SEA

W. J. Jenkins and H. D. Livingston

Artificial radionuclides introduced to the oceans during the last four decades have proved invaluable tools for study of many processes in marine water columns and sediments. Both global and close-in fallout of radioactivity from atmospheric nuclear weapons testing have distributed these radionuclides widely, and in amounts sufficient to be useful as tracers. An additional source of considerable significance and tracer potential comes from coastal discharges of European nuclear fuel reprocessing wastes. The nature of these sources, types and amounts of radionuclides introduced and the time histories of their introduction generate a variety of tracer distributions which illuminate a broad spectrum of physical and chemical processes active over a wide range of time scales.

Depending on their respective chemistries, artificial radionuclides have been demonstrated to exhibit both conservative and non-conservative properties in the oceans. Some examples are given of the uses made of soluble, conservative tracers for the study of oceanic transport processes and of non-conservative tracers for studies of processes which move them to, and mix them within, marine sediments. Sampling and measurement techniques which have been used in these studies are described.

Knowledge of contemporary distribution patterns of artificial radionuclides and their past evolution in the water and sediments forms the basis for predictions of future changes in these patterns, over both long and short time scales, and permits strong tests of models of the physical and chemical processes responsible. Studies of the future evolution of these tracer distributions will extend our knowledge of these processes to the longer time scales of planetary scale processes, and will begin to give us insight into the climatic variability of the shorter time scale processes.

In the future we can expect new types and forms of artificial radionuclides to be measurable in the ocean and usable as potential tracers. These will arise from (1) genetic radioactive decay of radionuclides now in the oceans, (2) biogeochemical modification of the chemical species present, (3) input from additional

sources which have introduced, or may introduce in the future, radionuclides not present or measurable now. New techniques will be helpful in measurement of these new radionuclides and to refine and improve ongoing studies. Future planned releases of artificial radionuclides are presently hard to predict -- being dependent on both technological and political developments. Based on recent developments in the field an attempt is made to predict the directions in which these tracer studies are likely to move in the 1980's.

In press: Oceanography: The
Present and Future, Springer
Verlag, New York, 1982.

Supported by: DOE Contract EY-76-S-02-
3563; and NSF Grants OCE78-21734
and OCE79-19815.

HELIUM ISOTOPIC VARIATIONS IN THE MANTLE BENEATH THE NORTH ATLANTIC OCEAN

M. D. Kurz, W. J. Jenkins, J. G. Schilling
and S. R. Hart

We have determined the helium concentrations and helium isotopic ratios for a set of basaltic glass samples dredged from the Mid-Atlantic Ridge between 30° and 53° North latitude. The total helium concentrations vary between $< 1 \times 10^{-8}$ ccSTP/gram and 1.4×10^{-5} ccSTP/gram. Most of this variation can be accounted for by gas loss on the seafloor via vesiculation, since the samples with the lowest concentrations have extremely high vesicularities. Analysis of the plagioclase phenocrysts from one of the samples suggests that helium behaves as an incompatible element ($K_D \ll .01$). The results of *in vacuo* crushing and melting experiments confirm that there is no helium isotopic fractionation during melt-vesicle or melt-plagioclase partitioning. The variations in $^3\text{He}/^4\text{He}$ ratio along the ridge must therefore be interpreted as a result of heterogeneity within the oceanic mantle. The $^3\text{He}/^4\text{He}$ ratios for this set of samples range from 6.8 to 11.1 times the atmospheric ratio. Using the strontium analyses performed on the same samples by White and Schilling (1978), there appears to be an overall negative correlation between $^{87}\text{Sr}/^{86}\text{Sr}$ and $^3\text{He}/^4\text{He}$. In detail however, there are two distinct provinces; north of 50°N and south of 33°N the basalts are characterized by a trend toward high $^3\text{He}/^4\text{He}$ ratios and high $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, while the region between 33° and 52°N is characterized by a trend toward low $^3\text{He}/^4\text{He}$ ratios and high $^{87}\text{Sr}/^{86}\text{Sr}$ ratios. Since primitive mantle should retain more primordial ^3He , the low $^3\text{He}/^4\text{He}$ trend requires the presence of a mantle reservoir which has a

lower $^3\text{He}/(\text{Th} + \text{U})$ and higher Rb/Sr . The generation of this component requires separation between He and Th + U, either by selective loss of He (degassing), or the addition of Th + U.

In press: Earth and Planetary Science Letters.

Supported by: NSF Grant EAR77-23170.

HELIUM ISOTOPIC SYSTEMATICS OF OCEANIC ISLANDS: IMPLICATIONS FOR MANTLE HETEROGENEITY

M. D. Kurz, W. J. Jenkins and S. R. Hart

The helium isotopic systematics of a number of ocean islands, as determined from the gases contained in basaltic phenocrysts and glasses, are characterized by two distinct trends when plotted against $^{87}\text{Sr}/^{86}\text{Sr}$. We believe that the most reasonable explanation of these trends is "mixing" between three components in the mantle. In this model, one component (the source for mid-ocean ridge basalts) with a $^3\text{He}/^4\text{He}$ ratio of roughly $8-9 \times$ atmospheric and $^{87}\text{Sr}/^{86}\text{Sr}$ of roughly .7025, mixes with two other reservoirs, both of which have higher $^{87}\text{Sr}/^{86}\text{Sr}$ values, but different He/He . One of these sources, which is tapped by volcanics on Iceland and Hawaii, is characterized by higher $^3\text{He}/^4\text{He}$ ratios, which is consistent with the presence of more primordial helium. Glasses from the Loihi Seamount have the highest $^3\text{He}/^4\text{He}$ ratio ($24.5 \times$ atmospheric), which is closest to the primordial end-member. The other mantle source, tapped by volcanics on islands such as Tristan da Cunha and Gough, has lower $^3\text{He}/^4\text{He}$ (as low as $6 \times$ atmospheric), indicating the presence of more radiogenic helium. Since basalts from Tristan da Cunha and Gough lie near "bulk earth" on the Sr-Nd anti-correlation line, this latter result requires the re-evaluation of the hypothesis that the mantle sources for Tristan da Cunha and Gough are "undepleted" or primitive. The helium isotope results for these islands are more consistent with a mixture of a recycled oceanic crustal component with the mid-ocean ridge basalt reservoir.

In press: Nature.

Supported by: NSF Grant OCE79-09379 and USGS Contract 14-08-0001-G541.

IN SITU CHEMISORPTION OF RADIOCESIUM FROM SEAWATER - MODIFIED METHODOLOGY

Don R. Mann and Susan A. Casso

A novel approach to in situ extraction of Cs radionuclides from seawater is described which offers many advantages over previous methods. Cesium (stable and radioactive) is partially stripped from seawater as it passes in series through a tandem cartridge consisting of twin beds of ion exchange resin impregnated with cupric ferrocyanide. An in-line prefilter collects particulate matter and an in-line flow meter measures the volume of water which passes through the cartridge. We demonstrate that, when seawater passes through this cartridge at a constant flow rate, collection efficiencies of each bed are the same, allowing the calculation of original seawater Cs nuclide concentration to be made from measurements of the activities on each bed and the volume of water passed through the cartridge. The cartridge is made of inexpensive, readily available PVC pipe fittings and is easily deployed under various field conditions. We describe improvements in resin preparation and procedures for the desorption and the radiochemical purification of the collected Cs. Thousands of liters of seawater can be stripped of Cs in this way, permitting substantial improvement in the sensitivity of measurement of ^{134}Cs , ^{137}Cs or of their ratio.

In press: Marine Chemistry.

Supported by: DOE Contract DE-AC02-81-EV-10694.

GG-1

DEPARTMENT OF GEOLOGY AND GEOPHYSICS

John I. Ewing, Department Chairman

GEOLOGY and GEOPHYSICS

BIOGEOCHEMISTRY

ON PRODUCING A GENERAL MODEL FOR THE
ACCURATE DESCRIPTION OF BIOGENIC SILICA
DISSOLUTION IN NATURAL WATERS: PART I
INTER-RELATION AND LABORATORY TESTING OF
EXISTING EQUATIONS

David C. Hurd and Scot Birdwhistell

The dissolution of biogenic silica can be described both by the disappearance of the solid and by the build-up of dissolved silica in solution. The equations describing both processes are mathematically interrelated. Existing equations, which predict dissolution rate as a function of temperature, have been extended to include the effects of particle size and surface energy on solubility. Estimated surface energies on the order of 120 erg/cm² fit the data well for both interconnected rods and uniform spheres. V_{dis} , a dissolution rate constant describing the disappearance of the solid phase, can now be predicted as a function of specific surface area as well as temperature for various particle geometries; this in turn will allow for a more accurate interpretation of Nelson's field data.

In press: American Journal of Science.

Supported by: NSF Grant OCE79-25412 and
ONR Contract N00014-79-C-0071, NR
083-004.ON THE ESTIMATION OF MINIMUM MECHANICAL
LOSS DURING AN IN SITU DISSOLUTION
EXPERIMENT

David C. Hurd and Kozo Takahashi

Dissolution rates of biogenic silica as a function of depth in the ocean were calculated for the variables temperature, pH, dissolved silicon concentration, and measured surface area of radiolarian skeletons. These rates were compared with observed percent weight losses of a single species of radiolarian skeletons during an *in situ* dissolution experiment. The relationship between increasing mechanical weight loss and increasing total dissolution was linear, suggesting the usefulness of this mathematical approach to dissolution experiments.

In press: Marine Micropaleontology.

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

BIOMINERALOGY

CHANGES IN THE PHYSICAL AND CHEMICAL
PROPERTIES OF BIOGENIC SILICA FROM
THE CENTRAL EQUATORIAL PACIFIC:
PART III, SPECIFIC PORE VOLUME, MEAN
PORE SIZE AND SKELETAL ULTRASTRUCTURE
OF ACID-CLEANED SAMPLESDavid C. Hurd, H. Stuart Pankratz,
Vernon Asper, James Fugate
and Henry Morrow

The specific surface area, specific pore volume and skeletal porosity of diatoms and polycistine radiolaria have decreased by a factor of about 50 during the last 40 mybp. These changes occur as a result of variations in thickness of an outer porous layer. The properties of the outer porous layer are generally uniform and have a mean pore radius of 33 ± 10 Å. The outer layer has been detected by using nitrogen, water, and methyl red adsorption as well as transmission electron microscopy. Closed pores also exist that density data suggest may contain water. The outer porous layer appears to result from dissolution processes because it has not commonly been found in preliminary investigations of polycistine radiolaria from sediment traps.

Published in: American Journal of
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GEOLOGY

PETROGRAPHY AND IMPLICATIONS OF
CONTINENTAL ROCKS FROM THE AGULHAS
PLATEAU, SOUTHWEST INDIAN OCEAN

Richardson B. Allen and Brian E. Tucholke

Reported seismic refraction and reflection profiles indicate that the Agulhas Plateau is a continental fragment that was rifted from the Falkland Plateau and intruded by basaltic magmas during the early opening of the South Atlantic. Dredge samples recovering a characteristic suite of low- to high-grade continental metamorphic rocks, as well as associated indurated sedimentary rocks, and mafic and silicic volcanic samples, support this origin and evolutionary history. Both the petrography of the gneiss specimens and K-Ar age dates of 1074 ± 36 m.y. and 478 ± 17 m.y. on fresh biotites from two of these

rocks are compatible with petrography and ages of the formerly adjacent continental rocks of southern Africa, the Falkland Islands, Falkland Plateau and Antarctica.

Published in: *Geology*, 9, 463-468.

Supported by: NSF Grants OCE76-21782 and DPP78-20629.

THE CONTINENTAL-OCEANIC CRUSTAL TRANSITION OFF SOUTHWEST AFRICA

James A. Austin, Jr. and Elazar Uchupi

More than 2300 km of 48-trace, 12-fold seismic reflection profiles are used to examine the nature of the continental-oceanic crustal boundary off southwest Africa. South of the Orange River, faulted crust which we believe to be continental in origin can be traced seaward to the 3km isobath. The transition to oceanic basement occurs in a zone 30 to 40 km wide beneath the continental rise. While structural details are obscured by a thick, prograded wedge of pre-AII (prelate Early Cretaceous) overburden, oceanic crust at the contact is not older than magnetic anomaly M9 (126-121 my AB.P.).

North of the Orange River, a pronounced hinge in continental crust correlates with the G magnetic anomaly of Rabinowitz (1976). Seaward of the hinge, a complex fault block terrain is evident. Oceanic basement cannot be traced with any certainty landward of anomaly M4.

Intracontinental stretching and associated volcanism appears to have been important in the early history of this margin. Continental rifting and local dike intrusion explains the presence of lineated potential field anomalies previously interpreted as seafloor spreading anomalies. The seismic data also suggest that initiation of spreading in the Cape Basin postdates by 4-9 my the Valanginian age derived from previous plate tectonic reconstructions of the South Atlantic.

In press: *American Association
Petroleum Geologists Bulletin*.

Supported by: NOAA Sea Grant NA80AA-D-00077.

IGNEOUS AND METAMORPHIC ROCKS OF THE NORTHERN DOMINICAN REPUBLIC: AN UPLIFTED SUBDUCTION ZONE COMPLEX

Carl O. Bowin and Fred Nagle

Igneous rocks exposed on the north coast of the Dominican Republic include

volcanic rocks (largely andesite), tonalite, diorite, gabbro, and serpentized peridotite. Metamorphic rocks include amphibolite, garnet amphibolite, gneiss, quartz-calcite, chlorite-muscovite schist, marble, glaucophane schist and eclogite. Chaotic rock assemblages occur in the Puerto Plata region and in an area southeast of Gaspar Hernandez. The chaotic collection at Puerto Plata are here interpreted to be a Late Cretaceous to Middle Eocene subduction zone that was uplifted in the Middle to Late Eocene, and unconformably overlain by Upper Eocene clastic sediments.

Published in: *Transactions of the Ninth
Caribbean Geological Conference*.

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

CONTRASTED ABYSSAL BASALT LIQUIDUS TRENDS: EVIDENCE FOR MANTLE MAJOR EL. HETEROGENEITY

Wilfred B. Bryan and Henry J.B. Dick

Natural submarine basalt glasses define liquidus trends which may be summarized as curvilinear regression lines in the normative plagioclase-pyroxene-olivine ternary. Individual basalt suites separated in time or space may define distinct, subparallel trends which are distinguished by different levels of plagioclase saturation. These contrasted trends can be equated with systematic differences in major element composition. Comparison of two contrasted sets of trends to available experimental and petrographic data confirms the similarity of the natural basalt trends to those predicted by one-atmosphere experiments, in general agreement with earlier studies based on whole-rock data.

In press: *Earth and Planetary Science
Letters*.

Supported by: NSF Grant OCE77-26842.

MAGMA CHAMBER PROFILES FROM THE BAY OF ISLANDS OPHIOLITE COMPLEX: IMPLICATIONS FOR CRUSTAL-LEVEL MAGMA CHAMBERS AT MID-OCEAN RIDGES

J.F. Casey and Jeffrey A. Karson

Models of the oceanic lithosphere derived from constraints imposed by the geology of ophiolite complexes require a magma chamber to produce the cumulate* and other plutonic portions of the oceanic crust and upper mantle. We present evidence from the Bay of Islands Ophiolite

Complex which indicates that layered plutonic rocks have not formed solely due to differential crystal settling to the horizontal floor of a magma chamber, but have formed largely by heterogeneous nucleation and in situ crystallization along gently inclined as well as steeply inclined bounding surfaces of a large magma reservoir. Coherent, well-defined and systematically oriented large-scale accurate patterns described by mesoscopic igneous layering have been identified in the plutonic sections of two ophiolite massifs in the Bay of Islands Complex. These layering patterns appear to outline the shape of a large continuously-evolving steady-state magma chamber that extended along a ridge axis and was terminated at a transform fault intersection.

*The textural terminology and classifications systems developed for rocks believed to have originated by crustal settling^{36,41} can be applied to many coarse-grained plutonic rocks regardless of their origin. We do not interpret layered plutonic rocks of the Bay of Islands Ophiolite as cumulates in the genetic sense, but have chosen to use the terms cumulate, cumulus, primocryst, intercumulus and postcumulus because they are meaningful in a descriptive sense regardless of the rocks origin and because a satisfactory, non-genetic terminology is not well-developed. For further discussions the reader is referred to McBirney and Noyes³³ and Campbell³².

Published in: Nature, 292, 295-301.

Supported by: NSF Grant EAR76-14459.

QUATERNARY CIRCULATION OF THE ANTARCTIC CIRCUMPOLAR CURRENT

Bruce H. Corliss

Deep sea benthonic foraminiferal data from 4 Eltanin piston cores (E48-22, E48-28, E49-18, E49-23) are used to determine deep water circulation conditions in the Southern Ocean during the last 450,000 years. The faunal data exhibit glacial-interglacial oscillations which are interpreted to reflect a reduced influence of North Atlantic Deep Water upon the Antarctic Circumpolar Current during glacial intervals.

Supported by: NSF Grants DPP78-21105 and DPP80-20479.

GEOLOGICAL LIMITS OF THE "CONTINENTAL SHELF"

Kenneth O. Emery

Continental shelf is an old and well understood physiographic term. In the search for revenues from high-technology ocean-floor mining the United Nations Third Law of the Sea Conference has redefined "continental shelf" to include the entire continental margin (continental shelf, slope, and rise) notwithstanding the fact that the underlying geology oceanward of the continental slope is very different from the geology landward of it. In addition, the outer limit of the "continental shelf" was defined in an arbitrary and artificial manner. These legal definitions have no significance for science, and their usefulness for world economics and politics remains to be seen.

Published in: Ocean. Development and International Law, 10, 1/2, 1-11.

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SEA-LEVEL CHANGES IN THE WESTERN PACIFIC WITH EMPHASIS ON CHINA

K.O. Emery and Yu Fanghu

Tide-gauge stations along the coasts of the western Pacific Ocean including those of China reveal a general submergence of the land relative to sea level. The median subsidence rate during the past quarter-century at eight stations of China and Hong Kong is about -2.5 mm/year, in the range of measurements along most other coasts of the world. Year-to-year variations in relative sea level are large because of variations in discharge of the major rivers of China that in turn are controlled by variations in rainfall. Only three of the stations are on deltaic plains where submergence can be augmented by compaction of thick underlying sediments. Importance of these plains to agriculture and as sites for coastal cities indicates that additional tide-gauge stations be established and a search be made for older measurements of sea levels in order to learn whether or not the rate of coastal subsidence in China is increasing.

Published in: Oceanography et Limnology Sinica, 12, 297-310.

Supported by: Ocean Industries Program (partial support).

CLASSIFICATION OF SEACLIFFS

K. O. Emery and G. G. Kuhn

The general concavity or convexity of seaciff profiles results from relative rates of erosion by marine and subaerial processes, as well as from the positions of more resistant strata in the cliffs. Profiles supplemented by on-site examination serve to establish the activity and dominance of erosional processes and may indicate initiation of changes in regimen. Results of such studies can be useful for estimating stability for residences and highways at the top, face, and bottom of seaciffs to avoid unexpected destruction. Generally increased erosion and retreat of seaciffs are in prospect because of regionally wetter and stormier weather, rising sea level, and increased activities of man.

In press: Geological Society America.

Supported by: Ocean Industries Program (partial support).

THE EFFECT OF PRESSURE ON THE SOLUBILITY OF 11 SILICATES IN 20°C, pH8 SEAWATER

James W. Griffin and David C. Hurd

All of the silicate minerals studied (kaolinite, chlorite, labradorite, illite, microcline, montmorillonite, sponge spicules, amorphous silica, quartz, albite and augite) showed an increase in their solubility (with respect to dissolved silica) with increasing pressure. The relative solubility increases ranged from 20 percent to 200 percent over the pressure range 1 to 612 atm. The change in partial molar volume calculated for quartz is $-17\text{cm}^3/\text{mole}$; that for sponge spicules and amorphous silica $-9\text{cm}^3/\text{mole}$. Increasing pressure actually appears to increase reaction rates in some minerals (kaolinite, montmorillonite and amorphous silica), decrease reaction rates in others (microcline, illite, chlorite and labradorite) and have no effect on the remaining silicates studied.

Supported by: ONR Contract
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SUBSEABED DISPOSAL OF NUCLEAR WASTES?

Charles D. Hollister, D. Richard Anderson
and G. Ross Heath

Fine-grained clay formations within stable (i.e. predictable) deep-sea regions away from lithospheric plate boundaries and productive surface waters have attractive

properties that might serve to permanently isolate radioactive waste. The most important characteristics of such clays are their vertical and lateral uniformity, low permeability, very high cation retention capacity, and potential to self-heal when disturbed. The most attractive abyssal clay formation (oxidized red clay) covers nearly 30 percent of the sea floor and, hence, 20 percent of the earth's surface.

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and 13-2559.

NUCLEAR WASTES BENEATH THE DEEP SEA FLOOR?

Charles D. Hollister and David A. Deese

Projections of energy demands for the year 2000 show that nuclear power will likely be one of our major energy sources. But the benefits of nuclear power must be balanced against the drawbacks, including its by-product: radioactive waste. While it may become possible to completely destroy or eliminate these wastes, it is most likely that we will have to dispose of some dangerous waste on Earth in such a way as to assure their isolation from man for periods on the order of hundreds of thousands of years.

Undersea regions away from plate boundaries, continental margins, and the relatively productive edges of major current gyres offer some conceptual promise for waste disposal because of their geologic stability and comparatively low organic productivity. The technical feasibility of permanent disposal beneath the deep sea floor cannot accurately be assessed with present knowledge, and there is a need for thorough study of the types and rates of processes that affect this part of the earth's surface. Basic oceanographic research (supported by USDOE) aimed at understanding these processes is yielding answers that apply to this societal need.

The general requirements for a nuclear waste repository anywhere are:

1. The area must have a history of stability (from 10^6 - 7 years ago through the present).
2. It must be isolated from man's unpredictable activities and thus must not interfere with established or likely resources.
3. Disposal is assumed to be permanent, yet emergency retrieval options should be developed.

4. Above all, the site plus the disposal method must act to preclude any significant release of the radionuclides while it is dangerous to the biosphere.

In press: La Recherche.

Supported by: Sandia Laboratories
Contract 13-2559.

HYDROTHERMAL MOUNDS AND YOUNG OCEAN CRUST OF THE GALAPAGOS: PRELIMINARY DEEP SEA DRILLING RESULTS, LEG 70

Jose Honnorez,
Richard P. Von Herzen, et. al.

A total of 32 holes at 5 sites near 1°N, 86°W drilled on Deep Sea Drilling Project (DSDP) Leg 70 (November–December 1979) provide unique data on the origin of the hydrothermal mounds on the south flank of the Galapagos spreading center. Hydrothermal sediments, primarily Mn-oxide and nontronite, are restricted to the immediate vicinity of the mounds (<100m) and are probably formed by the interaction of upward-percolating hydrothermal solutions with sea water and pelagic sediments above locally permeable zones of ocean crust. Mounds as much as 25 m in height form in less than a few $\times 10^5$ yrs, and geothermal and geochemical gradients indicate that they are actively forming today. The lack of alteration of upper basement rocks directly below the mounds and throughout the Galapagos region indicates that the source of the hydrothermal solutions is deeper in the crust.

Published in: Geological Society
of America Bulletin, Part I, 92,
457–472, July 1981.

Supported by: NSF Grant OCE79–19234.

PHYSICAL AND CHEMICAL PROPERTIES OF BIOGENIC SILICA

David C. Hurd

Having read some seven chapters about the importance of silica in a variety of environments, the reader may now wonder why a separate chapter should be devoted to the chemical and physical properties of siliceous skeletons. To me, the answer lies in the general agreement that organisms quite regularly perform precipitation processes of considerable magnitude which would never occur spontaneously under the conditions in which the organisms are operating. The oceans, rivers and lakes are all quite under-

saturated with respect to the solubility of biogenic silica, yet diatoms, radiolarians, silicoflagellates and sponges together probably precipitate on the order of 10^{16} grams of silica annually. Most of this material seems to dissolve and does not enter into the sedimentary record. There are many ways of describing the rates of dissolution and the various physical properties of biogenic silica depending on the purpose of the investigator. What follows is a series of discussions about the siliceous skeletons of mostly radiolarians and diatoms as applied to understanding the solid itself and in formulating recycling models which are consistent with the physical reality of the solid as I understand it thus far. At the end of some sections, I have also tried to pose additional questions regarding future research about biogenic silica using various techniques, and where suitable, references which may offer a useful beginning for the researcher have been included.

In press: Silicon Geochemistry and Biogeochemistry.

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

CONTINENTAL/OCEANIC CRUSTAL TRANSITION IN THE GULF COAST GEOSYNCLINE

Abou-Bakr K. Ibrahim and Elazar Uchupi

Data from four seismic refraction profiles from the East Texas Shelf were combined with previously collected information to determine the location of the transition from continental to oceanic crust beneath the Gulf Coast geosyncline. Northwest of Cuba, between the Florida and Campeche escarpments, the change from continental to oceanic crust takes place at a depth of over 3000m. Farther northwest along the eastern flank of the Mississippi embayment the transition occurs at a depth of about 2500 meters and on the embayment itself inboard of the coast. Off south Texas the continental/oceanic crustal contact is near the shelf's edge. Maximum sediment accumulation has taken place along the contact between the two crustal types.

In press: AAPG Memoir Hedberg Volume.

Supported by: NOAA Sea Grant
NA80AA–D–00077.

STABLE ISOTOPIC STRATIGRAPHY AND PALEOCEANOGRAPHY OF DSDP SITES 502 AND 503

Lloyd D. Keigwin, Jr.

Stable isotopic analyses of mono-

specific planktonic foraminifera (*G. quadrilobatus* group) and monogeneric benthic foraminifera (*Cibicides* spp.) from Late Neogene Atlantic DSDP Site 502 and Pacific Site 503 were carried out to determine the paleoceanographic changes resulting from the Late Neogene uplift of the Panama Isthmus and climatic cooling.

In general, Late Miocene and Pliocene isotopic results at each site are similar to those of previous studies for this time interval, which document the Late Miocene (6 Ma) carbon isotopic shift and the inferred growth of permanent Northern Hemisphere continental ice sheets beginning at about 3.2 Ma. Comparison for Atlantic-Pacific planktonic-benthic isotopic data for four stratigraphic intervals (~6-8, ~5-6, ~3-5, and ~2-3 Ma) suggests that increasing isolation of Atlantic and Pacific low latitude waters may be related to the emergent Panama Isthmus. The Atlantic-Pacific contrast of benthic foraminiferal $\delta^{13}\text{C}$ increased in two steps from 0.60‰ (the modern contrast) at about 6 Ma and 3 Ma. The first increase (0.15‰) may represent the end of previously limited deep water communication between the Atlantic and Pacific at the present location of Panama. The second increase (0.25‰) may be due to increased production of North Atlantic Deep Water. This probably reflects the development of modern deep-sea circulation.

Planktonic foraminiferal $\delta^{18}\text{O}$ begins to increase in Atlantic Site 502 at 4.2 Ma and may reflect increasing salinity of the North Atlantic Ocean due to diminishing surface water exchange across Panama. This $\delta^{18}\text{O}$ increase, is clearly shown by contrasting Atlantic-Pacific planktonic foraminiferal $\delta^{18}\text{O}$ as well as the $\delta^{18}\text{O}$ of planktonic and benthic foraminifera at Site 502. This inferred surface-water salinity increase begins at the time of increasing Atlantic-Pacific planktonic foraminiferal provinciality.

In press: DSDP Initial Reports, 68.

Supported by: NSF Grant OCE79-14594 (to URI).

PETROGRAPHY AND GEOCHEMISTRY OF BASALTIC ROCKS FROM THE CONRAD FRACTURE ZONE ON THE AMERICA-ANTARCTICA RIDGE

Anton P. le Roex and Henry J.B. Dick

Intrusive and extrusive basaltic rocks have been dredged from the Conrad fracture zone (transecting the slow-spreading America-Antarctica Ridge). The majority of rocks recovered are holocrystalline with the dominant mineral assemblage being

plagioclase plus clinopyroxene with or without minor Fe - Ti oxides (olivine occurs in only three samples) and many of the samples show evidence of extensive alteration. Secondary minerals include chlorite, actinolite, K- and Na-feldspar, analcite and epidote. In terms of bulk chemistry the rocks are characterized by their generally evolved and highly variable compositions (e.g. $\text{Mg}^* = 0.65 - 0.35$; $\text{TiO}_2 = 0.7 - 3.6\%$; $\text{Zr} = 31 - 374\text{ppm}$; $\text{Nb} = 3 - 21\text{ppm}$; $\text{Y} = 17-96\text{ppm}$; $\text{Ni} = 100 - 9\text{ppm}$), but with respect to the immobile incompatible element ratios (e.g., Zr/Nb , Y/Nb , La/Sm) are similar to 'normal' or depleted MORB.

Quantitative major and trace element modeling indicate that most of the variation observed can be attributed to low pressure fractional crystallization of plagioclase plus clinopyroxene in approximately equal proportions with or without minor Fe - Ti oxides. The range in composition can be accounted for by up to 76 percent fractional crystallization. Although ferrobasalts have not frequently been associated with slow spreading ridges, the extreme differentiation observed in the Conrad F.Z. basalts implies some additional constraint other than spreading rate on the formation of ferrobasalt and reaffirms the importance of extensive crustal differentiation during the production of this basalt type.

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Eocene to Oligocene Isotopic Record in the Bay of Biscay

Kenneth G. Miller and William B. Curry

We present oxygen and carbon isotope records of Eocene to Oligocene benthic foraminifera for two Bay of Biscay DSDP sites (119 and 401). A 1.9‰ increase occurs in $\delta^{18}\text{O}$ of benthic foraminifera from a middle Eocene minimum (Zones P10-P11) to an earliest Oligocene maximum (Zone NP21). Approximately 1.4‰ of the increase in benthic foraminiferal $\delta^{18}\text{O}$ occurs during the late Eocene to earliest Oligocene (Zones P15/16-NP21). Previously published results from other North Atlantic DSDP sites (400A and 398) have significantly lower $\delta^{18}\text{O}$ values in benthic foraminifera, some by as much as 2‰. We believe that these differences result from diagenetic alteration of the sediments in the deeper-buried Sites 400A and 398.

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DEVELOPMENT OF ABYSSAL CIRCULATION SOUTH OF THE GREENLAND-SCOTLAND RIDGE

Kenneth G. Miller and Brian E. Tucholke

Seismic lithostratigraphic, faunal, and isotopic evidence from the western and northern North Atlantic indicates that formation of northern sources of strongly circulating bottom water began in late Eocene to early Oligocene time. The widely distributed reflector R4 correlates with an unconformity eroded along basin margins at the Eocene-Oligocene boundary. A major benthic foraminiferal turnover in the deep southern Labrador Sea (DSDP Site 112) and a faunal reorganization in the Bay of Biscay correlate with this change in abyssal regime. The principal bottom water source is thought to be of Arctic origin; it entered the Norwegian Sea following separation of Greenland and Spitsbergen and flowed south over the Greenland-Scotland Ridge through the Faeroe Bank Channel and possibly across a sill adjacent to Greenland. This flow may have been supplemented by dense water from the Arctic region via Nares Strait and Baffin Bay, and from cooling of saline surface water south of the Greenland-Scotland Ridge and in the Labrador Sea. Current-controlled sedimentation and erosion, often of a chaotic nature, continued above reflector R4 through the Oligocene, but the general intensity of abyssal circulation is thought to have decreased. Above reflector R2 (upper lower Miocene) current-controlled sedimentation became more coherently developed, and the major phase of sedimentary drift development occurred. We interpret this to be a result of a further general reduction and stabilization of the abyssal circulation, possibly linked with degeneration of numerous fracture-zone conduits across the Reykjanes Ridge. The nature of the gross circulation has not changed significantly since that time although it has been punctuated by further climatic and tectonic events.

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Institute, Plenum Press.

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FINE-SCALE MORPHOLOGY AND STRUCTURE OF THE RIDGE AND TROUGH PROVINCE, UPPER CONTINENTAL SLOPE, SOUTHWEST FLORIDA

John D. Milliman, Thomas E. Pyle and
Michael Rawson

The ridge and trough province is an eroded and dissected foreset sequence that occurs along a 5 to 9 km wide-zone on the upper slope off southwest Florida. Observations from the submarine NR-1 show a series of three parallel ridges and intervening troughs within a water depth range of 384 to 436 m. Ridges consist of a series of vertical (or nearly vertical) sedimentary outcrops, each capped with what appears to be a manganese/phosphorite and/or limestone layer, and separated from one another by terraces of various widths. Contrary to previous speculation, no evidence of faulting was found. While the absence of rock samples precludes determination of age or composition of the sedimentary strata, it appears possible that these outcrops represent a continuation of the mid-Tertiary phosphoritic sequences found on the Pourtales Terrace and Blake Plateau.

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Science, 31, 134-140.

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MINERALOGY OF SEDIMENTARY FORMATIONS IN THE WESTERN NORTH ATLANTIC OCEAN: PRELIMINARY RESULTS

Peter Rothe and Brian E. Tucholke

Six sedimentary formations and two separate members recently were described by JANSÁ, et al. (1979) for the western North Atlantic Ocean basin. We have investigated the mineralogical composition of these lithostratigraphic units by qualitative X-ray diffraction analyses of about five hundred samples from DSDP Sites 105, 106, 386, 387 and 391. The sedimentary section studied, from bottom to top, consists of: argillaceous limestones (Cat Gap Fm.); limestones (Blake-Bahama Fm.); claystones and shales (Hatteras Fm.); zeolitic clay-stones (Plantagenet Fm.); nannofossil marls (Crescent Peaks Mbr.); siliceous oozes, clays, and cherts (Bermuda Rise Fm.); and hemipelagic muds (Blake Ridge Fm.) that locally contain redeposited shallow-water carbonates (Great Abaco Mbr.). The section ranges in age from Oxfordian at the base to Quaternary at the seafloor. Most of the formations and members described by JANSÁ, et al. (1979) have a characteristic mineralogical composition. Thus, it is possible to

recognize boundaries between formations and members by changes in mineral components, although these changes range from sharp to transitional. Within the same formation local differences in mineral spectra between sites can be explained by changing distance from terrigenous sources, lateral changes in surface paleoproductivity, and varying diagenetic conditions.

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CONTRASTED GLASS-WHOLE ROCK COMPOSITIONS AND PHENOCRYST REDISTRIBUTION AT IPOD SITES 417 and 418

Hubert Staudigel and Wilfred Bryan

Composition ranges of closely associated basalt glass-whole rock pairs from individual small cooling units approach the total known range of basalt glass and whole rock compositions at IPOD sites 417 and 418. The whole rock samples fall into two groups: one is depleted in MgO and distinctly enriched in plagioclase but has lost some olivine and/or pyroxene relative to its corresponding glass; and the other is enriched in MgO and in phenocrysts of olivine and pyroxene as well as plagioclase compared to its corresponding glass. By analogy with observed phenocryst distributions in lava pillows, tubes and dikes, and with some theoretical studies, we infer that bulk rock compositions are strongly affected by phenocryst redistribution by gravity settling, flotation, and dynamic sorting after eruption, although specific models are not well constrained by the one-dimensional geometry of drill core.

Compositional trends or groupings in whole rock data resulting from such late-stage processes should not be confused with more fundamental compositional effect products in deep chambers or during partial melting.

In press: Contributions Mineralogy and Petrology.

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SEISMIC ANISOTROPY OBSERVED IN UPPER OCEANIC CRUST

Ralph A. Stephen

Seismic anisotropy in the upper 1500 m of oceanic basement has been observed by polarization analysis of three-component borehole seismometer records. The most

convincing evidence for the anisotropy is shear wave splitting for explosive sources at four azimuths. Compressional wave particle motion deviations suggestive of anisotropy are also observed but they may be caused by lateral inhomogeneities. The anisotropy was not resolved by travel-time analysis. The observed velocities and particle motions in the horizontal plane can be modeled to within a standard deviation by assuming a perfectly elastic, homogeneous, anisotropic layer 2 with hexagonal symmetry and a horizontal symmetry axis. The most probable cause of the anisotropy is preferred crack orientation.

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Letters, 8, 865-868.

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THE OBLIQUE SEISMIC EXPERIMENT ON DSDP LEG 70

Ralph A. Stephen

A borehole seismic experiment was carried out in Hole 504B in the Costa Rica Rift area of the East Pacific. In this experiment the clamped borehole geophone was deployed deeper into oceanic crust (542 m) than on any previous seismic experiment. Comparison of travel-time data for the geophone at two depths in the hole and an ocean bottom hydrophone demonstrates clearly the advantages of borehole receivers in interpreting shallow crustal structure in the presence of a sediment layer (in this case 275 m thick). The lowest velocity directly detected by the ocean bottom receivers was 5.11 ± 0.18 k/s compared to 4.59 ± 0.09 k/s for the geophone clamped at 52 m into basement. A velocity model of the upper crustal structure consistent with the travel time data at all three levels was constructed. The scatter in observed layer 2 velocities can be explained by sampling different parts of the same velocity-depth structure and does not require lateral inhomogeneity. As in previous Oblique Seismic Experiments, no evidence for anisotropy was found from travel time analysis.

In press: DSDP Initial Reports.

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

Brian E. Tucholke

Several major seismic horizons in the

deep basin of the western North Atlantic Ocean have been calibrated according to age and physical and lithologic character by JOIDES drilling. Three horizons are discussed that are representative of the spectrum of stratigraphic relations in the basin. Horizon B, which ranges from Hauterivian to Barremian in age, correlates with a sharp upward transition from limestones to black clays coincident with a rise in the calcite compensation depth. In Eocene time, sediments enriched in biogenic silica were widely deposited, and subsequent diagenesis formed chert beds; the upper Lower to lower Middle Eocene surface of these cherts correlates with Horizon A^C which is one of the strongest and most widespread reflectors in the basin. Widely distributed borehole data indicate that both Horizon A^U and Horizon A^C normally occur within continuously deposited sedimentary sections. Beneath the continental rise, Horizon A^U correlates with a major unconformity eroded between Late Eocene and Early Miocene time by southward-flowing abyssal currents. The reflector may have limited chronostratigraphic significance because of lateral migration of the abyssal current system with time. Several simple models are used to assess potential age significance of the seismic and lithologic boundaries and are compared to borehole data.

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ORIGIN OF LONGITUDINAL TRIANGULAR RIPPLES ON THE NOVA SCOTIAN CONTINENTAL RISE

Brian E. Tucholke

From the time that current-produced bedforms were first recognized in the deep ocean, there has been continued effort to predict direction, intensity and variability of abyssal flow from the nature of seafloor irregularities (e.g., ref's. 1-3). Longitudinal triangular ripples (LTR's) constitute one class of intermediate-scale bedform (<20 cm high, meters long) that is becoming recognized as an important and geographically widespread predictor of bottom-current flow. Recent bottom photographs of LTR's fields on the lower continental rise off Nova Scotia show that the bedforms develop in fine grained, cohesive sediment with an alignment parallel to the regional contours and to mean current direction. LTR's appear to be deposited initially as "tails" behind large seafloor biologic mounds, and they subsequently propagate in the direction of mean current by crestward and down-current

sediment transport. This transport may be induced by short-term current flows that deviate randomly from the mean current direction and that cause formation of a separation bubble on one side or the other of the LTR crest.

In press: Nature.

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CONTINENTAL CRUST BENEATH THE AGULHAS PLATEAU, SOUTHWEST INDIAN OCEAN

Brian E. Tucholke, Robert E. Houtz
and Douglas M. Barrett

The Agulhas Plateau lies 500 km off the Cape of Good Hope in the southwestern Indian Ocean. The northern one-third of this large, aseismic structural high has topographically rugged acoustic basement, but acoustic basement of the southern two-thirds is anomalously smooth except for a 60-km wide zone with irregular relief that trends SSW through the center of the plateau. Seismic refraction profiles acquired on the southern plateau indicate that the zone of irregular acoustic basement overlies thickened oceanic crust and that continental crust, locally thinned and intruded by basalts, underlies several regions of smooth acoustic basement. The smoothness of acoustic basement probably results from erosion (perhaps initially subaerial) of topographic highs with redeposition and cementation of debris in ponds to form high-velocity beds. Basalt flows and sills also may contribute to formation of smooth basement of high velocity. The rugged crust of the northern plateau appears to be of oceanic origin. A plate reconstruction to the time of initial opening of the South Atlantic places the continental part of the southern plateau adjacent to the southern edge of the Falkland Plateau, which in turn abuts the western Mozambique Ridge. Both the Agulhas and Falkland Plateaus were displaced westward during initial rifting in the Early Cretaceous, and formation of a RRR triple junction at the northern edge of the Agulhas continental crust during middle Cretaceous time may explain the origin of the rugged, thickened oceanic crust beneath the northern plateau and the apparent extension of the continental crust and intrusion of basaltic magmas beneath the southern plateau. The relatively thin (<1km) sediment cover on the Agulhas Plateau makes this feature and comparable continental fragments ideal targets for investigation of early rifting processes in continental crust.

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MAPS OF SEDIMENT THICKNESS AND DEPTH TO BASEMENT IN THE WESTERN NORTH ATLANTIC OCEAN BASIN

Brian E. Tucholke, Robert E. Houtz and William J. Ludwig

More than 200,000 km of single-channel and multichannel seismic reflection data are used to construct an isopach map of sediment thickness and a map of depth to basement in the western North Atlantic Ocean basin, including the continental margins of eastern North America. Velocity regression equations and velocity estimates determined statistically from 17 provinces in the basin are used to convert reflection time in the sediments to thickness. The region between 15°N and 45°N latitude and between 40°W and 85°W longitude is portrayed in Mercator projection, at the scale 1.0 inch per degree longitude (1:4,377,908 at equator). Methods used for map preparation are outlined and prominent features in basement and sediment thickness are discussed.

In press: AAPG Bulletin and AAPG Map Series.

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NEOGENE AND QUATERNARY DEVELOPMENT OF THE LOWER CONTINENTAL RISE OFF THE CENTRAL U.S. EAST COAST

Brian E. Tucholke and Edward P. Laine

Interpretation of seismic reflection profiles and DSDP boreholes suggests two major phases in the Neogene and Quaternary development of the lower continental rise north of Cape Hatteras. Intense circulation of abyssal boundary currents in late Paleogene time eroded a regional unconformity (Horizon A⁴) along the lower continental rise, but by early Miocene time a first phase of very rapid sedimentation replaced this erosional regime. Sediments were injected into deep water principally at two points, forming large abyssal fans at the mouth of the Hudson Canyon and the Norfolk-Washington canyon. Along the eastern perimeter of these fans the abyssal Western Boundary Undercurrent, probably interacting with the western edge of the Gulf Stream, redistributed fine-grained

sediments to form the half-kilometer-high Hatteras Outer Ridge, which now parallels the regional bathymetric contours between Cape Hatteras and Hudson Canyon. The Gulf Stream Outer Ridge on the northwest Bermuda Rise probably was the northeasternmost extension of this outer ridge system. Migrating sediment waves and the presence of several unconformities demonstrate the importance of abyssal currents in constructing and shaping the Hatteras Outer Ridge. A second phase in development of the lower rise occurred near the onset of northern hemisphere glaciation 2.5-3.0 m.y. ago. At this time abyssal currents severed the connection between the Hatteras and Gulf Stream Outer Ridges and formed an erosional basin there. Shortly thereafter, this basin and the basins behind the Hatteras Outer Ridge began to be flooded by coarse turbidites. The turbidites eventually buried the western flank of the Hatteras Outer Ridge and ponded to form the present lower continental rise terrace. Several submarine channels breached the Hatteras Outer Ridge crest by 0.5 m.y. ago, allowing turbidity currents to flow down the exposed east flank of the outer ridge and onto the Hatteras Abyssal Plain. These turbidity currents have modified the shape and structure of many of the sediment waves on the outer ridge, but the Western Boundary Undercurrent continues to be important in sculpting the lower continental rise.

In press: AAPG Hedberg Conference Volume.

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G E O P H Y S I C S

GRAVITY AND GEOID ANOMALIES OF THE CARIBBEAN

Carl Bowin

The major features of gravity and geoid anomalies of the Caribbean region are illustrated and discussed. A novel residual geoid anomaly map shows good correlation with certain structural features, most prominent being the Puerto Rico and Middle America trenches, and the sedimentary wedge offshore northern South America. The strikingly similar spatial patterns of the two types of anomalies over these features indicate that the source of the mass anomalies causing the gravity and geoid anomalies are shallow. The residual geoid anomaly map shows localized variations along plate boundaries and the

term "spot tectonics" is used to identify these locations. An explanation for the differences existing on the northern Caribbean plate boundary on either side of tectonic spot at Longitude 18.5°W is presented.

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GRAVITY AND GEOID ANOMALIES OF THE PHILIPPINE SEA: EVIDENCE ON THE DEPTH OF COMPENSATION FOR THE NEGATIVE RESIDUAL WATER DEPTH ANOMALY

Carl Bowin

A broad regional negative free-air gravity anomaly (-10 mgal) occurs in the central part of the Philippine Sea, but geoid anomalies from GEOS-3 observations are positive. Subtraction of the geoid contribution from core-mantle boundary mass anomalies and deep mantle mass anomalies from the GEOS-3 geoid, yields a negative residual geoid anomaly consistent with the area of negative free-air gravity anomalies. Theoretical gravity-topography and geoid-topography admittance functions indicate that high density mantle at about 60 km depth can account for the magnitudes of the gravity and residual geoid anomaly and the 1 km residual water depth anomaly in the Philippine Sea. In that case, however, dense upper mantle material would be contrary to the anomalously slow surface wave velocity structure in the Philippine Sea as determined by Seekins and Teng (1977), although it could be compatible with a normal surface wave velocity structure in the west Philippine Basin as determined by Sacks and Shione (1981). Alternatively, the negative residual depth anomaly may be compensated for by excess density in the uppermost mantle, but the residual geoid and regional free-air gravity anomalies and a slow surface wave velocity structure might result from low-density warm upper mantle material lying beneath the zone of high-density uppermost mantle. From a horizontal disk approximation, the depth of the low-density warm mantle is estimated to be on the order of 200 km.

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GEOMAGNETIC SECULAR VARIATION RECORDED IN SEDIMENTS FROM THE NORTHEAST ATLANTIC OCEAN

Alan D. Chave and Charles R. Denham

A suite of piston cores, obtained in a high deposition rate area in the northeast Atlantic Ocean, were used for a detailed geomagnetic secular variation study over the time interval 25-127 kypb. Stratigraphic control was provided by planktonic foraminiferal assemblages with a resolution of a few thousand years. An inter-core correlation procedure was used on five sets of down-core stratigraphic data to show that a significant change in sedimentation rate occurred at the interglacial-glacial transition 60-80 kybp. The sedimentation rate was 4 cm/ky during glacial times, increasing to 7-9 cm/ky during interglacials.

Demagnetization analysis on 46 pilot samples from four piston cores reveals a stable remanence with a median demagnetizing field of 315±44 oe and a directional change of 4.8±2.2° over a 300 coercive force range. ARM reproduces the coercive force spectrum of the NRM over a 150-400 oe range. Down-core paleomagnetic time series were obtained in four cores covering parts of the interval 25-127 kybp. The directions correlate visually only in the glacial interval prior to 77 kybp. Relative paleo-intensity, determined by the pNRM/pARM method, is dominated by a long period (30 ky) signal that may be of climatic origin. Spectral analysis of the directions indicates long period (10 ky) looping of the geomagnetic field vector with no characteristic direction for the motion. In the interglacial interval 77-127 kybp no consistent result could be found, suggesting erosion or sediment rate variations that are not resolvable.

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ELECTROMAGNETIC INDUCTION FIELDS IN THE DEEP OCEAN NORTHEAST OF HAWAII AND IMPLICATIONS FOR MANTLE CONDUCTIVITY

Alan D. Chave, Richard P. von Herzen, Kenneth A. Poehls and Charles S. Cox

We have analyzed a 36-day recording of the natural electric and magnetic field variations obtained on the deep ocean floor northeast of Hawaii. The electromagnetic fields are dominated by tides which have an appreciable oceanic component, especially in the east electric and north magnetic components. The techniques of data analysis included singular value decomposition (SVD) to remove uncorrelated

noise. There are three degrees of freedom in the data set for periods longer than five hours, indicating a correlation of the vertical magnetic field and the horizontal components, suggesting source field inhomogeneity. Tensor response functions were calculated using spectral band averaging with both SVD and least squares techniques and rotated to the principal direction. One diagonal component, determined mainly by the north electric and east magnetic fields, is not interpretable as a one dimensional induction phenomenon. The other diagonal term of the response function indicates a rapid rise in conductivity to 0.05 mho/m near 160 km. No decrease in conductivity below this depth is resolvable. Polarization analysis of the magnetic field indicates moving source fields with a wavelength near 5000 km. Model studies suggest that the two dimensionality in the response function may be caused by motion in the ionospheric current system.

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THE POLARIZATIONS OF P-WAVES IN ANISOTROPIC MEDIA

Stuart Crampin, Ralph A. Stephen and Robert McGonigle

This paper examines P-wave propagation in anisotropic solids, and demonstrates the effect of anisotropy on the polarizations of quasi P-waves. The deviation of the polarization of the quasi P-wave from the propagation vector may be significant, but is in almost the same direction as the deviation of the group-velocity vector. Since the group-velocity, or energy propagation vector follows seismic ray paths, the apparent deviation is the difference of the polarization and group-velocity deviations and is small. Consequently, it may be easily overlooked, hidden by noise, or attributed to the effects of inhomogeneity.

In press: Geophysical Journal of R.A.S.

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NUMERICAL CORRELATION OF RECENT PALEOMAGNETIC RECORDS IN TWO LAKE TAHOE CORES

Charles R. Denham

Recent paleomagnetic fluctuations are smooth and well correlated in two short cores collected 28 km apart in Lake Tahoe.

Numerical pattern matching of the unit-vector time series data shows that the characteristic angular difference between the two records is only 110° for the past 3000 years. This compares favorably with the characteristic angular differences of 70° - 80° between adjacent samples within each core taken separately. The correspondingly high values of pairwise (between cores) and serial (within core) correlation are significant at 99.99 percent confidence. These data, collected and previously studied qualitatively by A.S. Goldstein, show that the sediment in Lake Tahoe can provide reliable Recent paleosecular variation records. The paucity of fine-scale paleomagnetic correlation between other cores from that basin is due likely to stratigraphic rather than rock magnetic difficulties.

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HEAT FLOW ON THE HAWAIIAN SWELL AND LITHOSPHERIC REHEATING

Robert S. Detrick, Richard P. von Herzen, S. T. Crough, David Epp and Udo Fehn

Most oceanic volcanic centers caused by hotspot activity are surrounded by sea floor that is unusually shallow for its age. There is increasing evidence that swells found on older sea floor, like the Hawaiian Swell, have formed from a broad-scale reheating and thinning of the lithosphere as it passes over a mantle hotspot. If the formation and subsequent disappearance of these swells are controlled by thermal processes, they should have an above-normal heat flux. We present here the results from 95 new heat flow measurements on the Hawaiian Swell. Along the older part of the swell the heat flow is 20-25% higher than the normal heat flow for crust of this age. This anomaly is consistent with the observed swell uplift. The shape and amplitude of the heat flow anomaly require that the reheating be largely confined to the lower half of the lithosphere.

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AN IMPLICIT FINITE-DIFFERENCE FORMULATION OF THE ELASTIC WAVE EQUATION

Steven H. Emerman, W. Schmidt and
Ralph A. Stephen

The problem with existing finite-difference formulations of the elastic wave equation is that they have a limited stability range, and the necessity of taking small time steps can result in excessively high computation costs. It is possible to formulate a finite-difference scheme which is stable for arbitrarily large time steps. However, the solutions obtained by the unconditionally stable scheme are unacceptably inaccurate for time steps outside the stability range of finite-difference schemes currently in use.

In press: Geophysics.

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ABSORBING BOUNDARY CONDITIONS AND THE STABILITY OF FINITE-DIFFERENCE SCHEMES FOR PROBLEMS IN MARINE SEISMOLOGY

Steven H. Emerman and Ralph A. Stephen

Finite-difference synthetic seismograms are being used to study elastic wave propagation through sea floor structures in which lateral and vertical heterogeneities occur over distances on the order of a seismic wavelength. By implementing absorbing boundary conditions rather than reflecting boundary conditions in the finite-difference schemes, it is possible to run smaller and less expensive models for the same structure.

Previous absorbing boundary finite-difference schemes for elastic wave propagation (Clayton and Engquist, 1977) lead to stable solutions only when $V_s/V_p \geq 0.46$, where V_s is shear wave speed and V_p is compressional wave speed. Clayton and Engquist (1977) have developed separate absorbing boundary conditions appropriate for the case $V_s = 0$. In order to simulate seismic wave propagation through sediments which have very low values of V_s/V_p , we have found an absorbing boundary finite-difference scheme which is stable for all $V_s/V_p > 0$. Our absorbing boundary condition approximates the elastic wave equation to zeroth order in (k_x/ω) , where k_x is the wave number parallel to the boundary and ω is frequency.

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RELATIVE SEA LEVELS FROM TIDE-GAUGE RECORDS

Kenneth O. Emery

Mean annual sea levels at 247 tide-gauge stations of the world exhibit a general rise of relative sea level of about 3 mm/year during the past 40 years. In contrast, general uplift of the land is typical of high northern latitudes where unloading of the crust by melt of Pleistocene ice sheets is significant. Erratic movements are typical of belts having crustal overthrusting and active volcanism. Short-term (5- and 10-year) records reveal recent changes in rates, but such short time spans may be so influenced by climatic cycles that identification of new trends is difficult, especially with the existing poor distribution and reporting of tide-gauge data.

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National Academy of Sciences, 77,
6968-6972.

UPPER CRUSTAL VELOCITY STRUCTURE IN THE ROSE AREA OF THE EAST PACIFIC RISE

John I. Ewing and G.M. Purdy

We describe a method to constrain the seismic velocity structure of the upper 500-800 m of young oceanic crust. Conventional interpretations of seismic refraction profiles provide little or no information concerning this shallowmost crust. The method described here requires the assumption of a linear velocity gradient and utilizes measured values of range, travel time and slowness of the observed refracted waves. Results are reported from several refraction profiles that sample crust between 0 m.y. and 4 m.y. in age on the flanks of the East Pacific Rise at 12°N. These data give an average gradient in the uppermost 800 m of the crust of 3.5 sec^{-1} and a velocity at the seafloor of 2.5 km/sec. Ray path and travel time modeling show that the refracted waves sampling the upper part of the crust are effectively masked by the reflections from its surface.

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Research.

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A HEAT FLOW SURVEY ON ANOMALY MO SOUTH OF THE BERMUDA RISE

Dan A. Galson and Richard P. von Herzen

We have obtained a suite of 42 closely-

spaced, acoustically-navigated, heat flow measurements on well-sedimented crust of anomaly M0 age (109 Ma) crust in the northwest Atlantic ocean (25°N, 68°W; 950 km south of Bermuda). The mean and standard deviation of the values obtained are 1.13 HFU ($\mu\text{cal}/\text{cm}^2\text{s}$) (47.3 mW/m^2) and .05 (2.1), respectively. Some of the variability is accounted for by refractive effects of the basement topography. Drill core data and our modeling suggest that the thermal conductivity contrast between sediments and basement rocks in this region is less than a factor of 1.6. The mean heat flow is close to the 1.1 HFU (46 mW/m^2) predicted by both the plate and boundary layer cooling models of the oceanic lithosphere. This is the first detailed comparison with theoretical cooling models on old Atlantic Ocean crust. Since the difference in surface heat flow (0.15 HFU) predicted by the two cooling models for the oldest observed oceanic lithosphere (180 Ma) is also not much larger than the range of uncertainty in our observations, discrimination between the two models on the basis of surface heat flow data alone may prove difficult.

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A MICROAFTERSHOCK SURVEY OF THE 1978 BERMUDA RISE EARTHQUAKE

Stuart P. Nishenko, G.M. Purdy and John I. Ewing

On March 24, 1978 a magnitude 6.1 intraplate earthquake occurred 380 km southwest of Bermuda near magnetic anomaly M4 (~118 mybp). A catalog of seismicity for the Bermuda Rise indicates that this is an area of significant intraplate seismicity in the western North Atlantic Ocean. The fault plane solution for the 1978 event is of thrust type and strikes 340°, in a direction intermediate to the trends of major fracture zones (300°) and abyssal hill topography (035°) in the area. The P axis of this mechanism is nearly horizontal and trends 259° subparallel to the absolute plate motion vector for North America. Teleseismic aftershock activity was observed for approximately 8 months after March 24 and appears to be swarmlike in nature rather than a typical mainshock-aftershock sequence. During June 18-28, 1978 we conducted a microaftershock survey of the area using ocean bottom hydrophones and recorded 250 events ($0 < m_b < 2$). These smaller events are located in a tight cluster 5-10 km northeast of the NEIS mainshock location. SP-P data from

microaftershocks recorded during this survey indicate a relatively narrow band of activity (~10 km wide), smaller than would be inferred based on NEIS aftershock locations alone. Many of the microaftershocks recorded exhibit prominent water wave phases, which have been used to further constrain the epicentral locations. The depths of these events, while not well determined, appear to be shallow (<5 km below the seafloor). Estimates of the b-value for the ten day recording period range from 1.10 to 1.50.

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THE CORRECTION FOR THE TRAVEL TIME EFFECTS OF SEA FLOOR TOPOGRAPHY IN THE INTERPRETATION OF MARINE SEISMIC DATA

G.M. Purdy

Problems associated with the application of topographic corrections to deep ocean marine seismic data are described. Synthetic travel time data are used to show that corrections for the delay time introduced by the water column are inferior to corrections for the true water path. Water path corrections place the shots at the ray entry points on the sea floor and require no assumptions concerning the structure under investigation and maintain the correct distribution of data with range. The water path correction can be most accurately applied during the stacking operation that transposes the observed data into intercept time-slowness space. There is then no requirement to make determinations of slowness, and for experiments involving sea floor receiver and surface shots the data may be transposed to the sea floor with complete objectivity. Water path corrected stacks from different locations may then be compared in the sure knowledge that any observed differences are due to real structural changes and not to topographic correction errors or to invalid assumptions of lateral homogeneity.

In press: Journal of Geophysical Research.

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THE VARIABILITY IN SEISMIC STRUCTURE OF LAYER 2 NEAR THE EAST PACIFIC RISE AT 12°N

G.M. Purdy

Seismic refraction data, collected

using a large airgun source and ocean bottom hydrophone receivers, show the uppermost 2 km of the crust in two areas on the flanks of the East Pacific Rise to be laterally homogeneous within the resolving power of our experimental technique. The two areas are 20 km and 40 km in extent, on 0.5 and 4 m.y. old crust respectively and are separated laterally by 110 km. A small but significant difference in structure exists between the two areas, the younger crust exhibiting the higher velocities. Ray tracing through laterally heterogeneous models of the shallow crust, the unusually careful calculation of corrections for seafloor topography and the objective comparison of datasets using the slant stacking approach suggest that the established apparent variability in shallow crustal structure may in part be an artifact of experimental and interpretative techniques. We propose a reasonable model for shallow crustal structure in which the isovelocity contours parallel the seafloor topography: this permits determination of lateral homogeneity of the velocity gradient in the shallow crust over the subdued topography of the East Pacific Rise, or in the deeper crust in general, where vertical velocity gradients are sufficiently small that topography has negligible effect on the velocity field.

In press: Journal of Geophysical Research.

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THE QUALITY OF THE MARINE MAGNETIC TAPE RECORDER

Hans Schouten and Charles Denham

The significance of short-wavelength marine magnetic anomalies ("tiny wiggles") depends on the temporal and spatial aspects of marine magnetic source layer emplacement. The episodicity and spatial scatter of volcanic emplacement in a seafloor spreading center determine the fidelity with which the paleomagnetic field intensity and direction are recorded in the marine magnetic anomaly source layer. Short-period paleomagnetic field variations or reversals cannot be distinguished from source layer noise if the emplacement of that source was too infrequent or too widely scattered. Existing data and analyses are not yet conclusive on the significance of the "tiny wiggles", or, on the quality of the marine magnetic tape recorder.

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ON THE QUALITY OF MARINE MAGNETIC ANOMALY SOURCES AND SEA-FLOOR TOPOGRAPHY

Hans Schouten, Charles Denham
and Woollcott Smith

The quality of marine magnetic anomaly sources is described with the power-density representation of a stochastic model of random temporal and spatial emplacement of the marine magnetic anomaly source in the oceanic crust. Typical values of sea-floor spreading and emplacement parameters define a high-fidelity process of recording and sea-surface detection of the paleomagnetic field reversals for spreading rates over 20 mm yr⁻¹. An analogous stochastic model is developed for the formation of sea-floor topography by normal faulting. It is shown that the random process of normal faulting observed in the inner walls of the FAMOUS rift valley can account for the quality of the adjacent West Rift Mountains topography.

In press: Geophys. J. R. astr. Soc.

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A COMPARISON OF FINITE DIFFERENCE AND REFLECTIVITY SEISMOGRAMS FOR MARINE MODELS I. SEA FLOOR INTERACTION

Ralph A. Stephen

Finite difference and reflectivity synthetic seismograms are compared for laterally homogeneous sea floor models with step and ramp discontinuities in elastic properties. Given suitable numerical parameters in each case acceptable agreement can be obtained. For step discontinuities between a liquid and a solid the implicit finite difference formulation of the elastic wave equation for heterogeneous media is unstable. It is necessary to explicitly introduce the boundary conditions at the interface and a suitable formulation correct to second order in the space increment is given. For ramp discontinuities between a liquid and a solid the finite difference formulation for heterogeneous media is stable and agrees with the reflectivity method when, in the latter case, the gradient is approximated by homogeneous layers thinner than one-fifth of the minimum compressional wavelength at the upper half-power frequency.

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TRAVEL-TIME CURVES FOR A SIMPLE SEA FLOOR MODEL

Ralph A. Stephen

This paper discusses travel-time relations for sources and receivers in a homogeneous layer over a layer in which velocity varies linearly with depth. For such a geometry there are three classes of behavior of the travel-time curve. The model is appropriate for studying the shallow-sea floor structure in a marine refraction experiment and an understanding of the travel-time curves which have been corrected for paths in the homogeneous layer, the time, range and ray parameter of a point on the curve are sufficient to obtain the velocity at the top of the gradient zone and the gradient.

Supported by: ONR Contract
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COUPLING PARAMETERS OF THE MIT OBS AT TWO NEARSHORE SITES

Anne M. Trehu and Sean C. Solomon

A model representing the coupling of an ocean-bottom seismometer (OBS) to the sea floor as a mass-spring-dashpot system satisfactorily explains the results of transient tests performed on different instruments during the Lopez Island intercomparison test. In this paper, we compare the results obtained for the MITS OBS at Lopez Island to results from similar tests at a dockside site at Woods Hole, Massachusetts. The vertical instrument response at the Lopez Island site shows a highly damped resonance at a frequency of 22Hz, whereas the response at the Woods Hole site shows a marked resonance at 13 Hz. The difference between the responses at the two sites can be qualitatively attributed to the difference between the surficial sediments.

In press: Marine Geophysical Research.

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LATERAL AND VERTICAL VARIABILITY IN CRUSTAL VELOCITY STRUCTURE IN A SMALL AREA OF THE NORTH ATLANTIC

Robert S. White and G.M. Purdy

The detailed velocity structure of a 70 by 35 km area of 6 to 10 Ma old crust on the flank of the Mid-Atlantic Ridge at 24°N was studied using 358 explosive charges and several hundred 16.4 liter

airgun shots fired into an array of eight ocean bottom hydrophones. Inversion of the first arrival refracted travel times shows that the crust comprises a normal oceanic section about 5 km thick with a steep velocity gradient in the upper crust increasing from about 3.5 km/sec at the sea floor overlying a typical oceanic layer 3 and a probable anisotropic mantle. Delay time function mapping using two datasets containing arrivals from layer 3 and from the mantle show that lateral variability is generally low over most of the survey area, with a small region of high delay times in the northwest corner caused by the presence of abnormal crust probably associated with a minor fracture zone. We find that the topography of the base of layer 2 is similar to that of the top, indicating that the normal faulting which occurs along the margins of the median valley extends down at least into layer 3. Our observations from mantle arrivals are consistent with a much flatter Moho which constrains possible models of crustal formation at the spreading center.

In press: Tectonophysics.

Supported by: ONR Contracts N00014-74-C-0262, NR 083-004 and N00014-79-C-0071, NR 083-004.

MARINE POLICY

PRE-CENOZOIC FAULTING ON THE EASTERN EDGE OF GEORGES BANK

Elazar Uchupi, James A. Austin, Jr.
and David H. Gever

The sedimentary sequence on the eastern end of Georges Bank is disrupted by faulting. The fault structures which displace sediments within 550 meters of the sea floor are probably due to the plastic flow of Early Jurassic salt.

In press: Northeast Geology.

Supported by: DOE Contract ID074-04094; NSF Grant OCE77-09421; Department of State Contract 1722-620214; NOAA Sea Grants 04-8-M01-149, NA79AA-D-00102 and NA80AA-D-00077.

MICROPALAEONTOLOGY

BIOSTRATIGRAPHY OF THE ANOMALINIDAE
CIBICIDIDAE IN THE SOVIET
TETHYAN PALEOGENE

Esfir Saperson and Martin Janal

The Paleocene and Eocene deposits of the Soviet Tethys are described biostratigraphically on the basis of a zonation utilizing species of the Anomalinidae and Cibicididae which fall into well-defined assemblages at the level of the stage. This zonation is linked to the system of local stages used for correlation of the Paleogene in the southern Soviet Union and defined strato-typically in the Bakhchisaray section of the Crimea. The assemblages of anomalinid and cibicidid species are geographically wide-spread, and many species occur in conditions of both platform and "geosynclinal" (tectonically active) deposition, as represented by Crimean and Turkmenian sections in the former case, and by North Caucasian sections in the latter. Assemblages are generally of the Midway type, but mixed assemblages of Midway and Velasco elements occur. Some species present in the Paleogene of the southern Soviet Union have also been recorded in Gulf Coast deposits of similar age. The more important species are treated systematically, and new species belonging to the Anomalinidae are described.

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4, 392-413.

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O T H E R

BENTHIC FORAMINIFERAL FAUNAL AND ISOTOPIC
DATA FOR THE POST-GLACIAL EVOLUTION
OF THE CHAMPLAIN SEA

Bruce H. Corliss, Allen S. Hunt and
Lloyd D. Keigwin, Jr.

Benthonic foraminiferal faunal and isotopic data from Champlain Sea sediments (approximately 12,500 to 10,000 Y.B.P. in age) in two piston cores from Lake Champlain provide a detailed, apparently continuous record of the evolution of the Champlain Sea. *Cassidulina reniforme* and *Islandiella helenae* are the dominant benthonic foraminifera during the initial phase of the Champlain Sea, and are

replaced by *Elphidium excavatum* forma *clavatum* and *Protelphidium orbiculare* as the dominant species during the remainder of the sea's history. The oxygen isotopic data show a gradual decrease in $\delta^{18}O$ between approximately 12,500 and 10,900 Y.B.P., followed by a more rapid decrease during the 10,900 to 10,000 Y.B.P. interval. The $\delta^{13}C$ data have a similar trend as $\delta^{18}O$, with generally decreasing values up the section. The isotopic and faunal data suggest that nearly marine conditions were present in the initial phase of the Champlain Sea, followed by gradually decreasing salinities and increasing temperatures as the sea evolved. The initiation of the rapid isotopic decrease at approximately 10,900 Y.B.P. marks the beginning of the largest environmental change in the history of the Champlain Sea, probably reflecting a major pulse of meltwater from the Laurentide Ice Sheet.

In press: Quaternary Research.

WHY CONSIDER SUBSEABED DISPOSAL OF
HIGH-LEVEL NUCLEAR WASTE ?

G. Ross Heath, Charles D. Hollister,
D.R. Anderson and Margaret S. Leinen

Large areas of the deep seabed warrant assessment as potential disposal sites for high-level radioactive waste because: (a) they are far from seismically and tectonically active lithospheric plate boundaries; (b) they are far from active or young volcanoes; (c) they contain thick layers of very uniform fine-grained clays; (d) they are devoid of natural resources likely to be exploited in the foreseeable future; (e) the geologic and oceanographic processes governing the deposition of sediments in such areas are well understood, and are remarkably insensitive to past oceanographic and climatic changes; and (f) sedimentary records of tens of millions of years of slow, uninterrupted deposition of fine grained clay support predictions of the future stability of such sites. Data accumulated to date on the permeability, ion-retardation properties, and mechanical strength of pelagic clay sediments indicate that they can act as a primary barrier to the escape of buried nuclides. Work in progress should determine within the current decade whether subseabed disposal is environmentally acceptable and technically feasible, as well as address the legal, political and social issues raised by this new concept.

In press: NOAA Symposium.

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JOINTING OF ARMORED POLYETHYLENE-INSULATED CABLE TO NEOPRENE JACKETED CONNECTORS

Wayne D. Spencer and David G. Aubrey

Since 1972 a large percentage of marine field instrumentation used by the Shore Processes Laboratory (SPL) of Scripps Institution of Oceanography (La Jolla, California) has been powered and monitored using cables. In 1975 the laboratory decided to change from neoprene jacketed cable to armored electrical cable in their data collection efforts. This armored cable was tough enough to withstand the nearshore ocean environment in which SPL field instruments were commonly employed, but was more expensive and less easily jointed than its neoprene jacketed counterpart. Difficulty in jointing was mainly due to the polyethylene insulation used in the construction of the cable (few readily available chemical compounds will bond to this insulating material). Many problems were encountered during the jointing of this armored cable, but joint reliability and reuse of jointed cable (without rejoining) after prolonged storage proved to be the most troublesome.

Four methods of jointing with histories of good performance have been used by SPL; these techniques were inexpensive, and readily implemented in the field. One encapsulation method used an epoxy to seal the joined conductors, while a second used polyurethane. A third technique implemented polyurethane washers molded to fit closely around the surfaces to be sealed; the washers were then compressed to create a watertight seal. A fourth method used heat shrink tubing, lined inside with polyurethane, to create a water tight cover around the connections. Recently the encapsulation methods have developed high failure rates; consequently these splicing methods are no longer used at SPL. The mechanical and the heat shrink methods have performed well in the field and have potential for future applications.

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PALEOBIOGEOGRAPHY

ASSESSMENT OF QUANTITATIVE TECHNIQUE IN PALEOBIOGEOGRAPHY

Bjorn A. Malmgren and Bilal U. Haq

A series of multivariate methods have

been compared to assess their effectiveness in extracting essential information out of a complex micropaleontological data-set. The data-set used for this experiment consists of relative frequencies (percentages) of Miocene coccolith taxa or groups of taxa in cores of the Deep Sea Drilling Project (DSDP) from the Atlantic Ocean. All methods tested are varieties of principal components analysis in R- and Q-mode, and "true" factor analysis. Various secondary rotational procedures ancillary to some of these methods are also tested.

A test, denoted Δ -Test, is developed, which assesses how well principal components or factors reproduce the data-set. Δ -Test may be used for determining the optimum number of principal components or factors, the most relevant rotational procedure, and thus the most suitable analytical technique. The Δ -Test does not rely on mathematical testing, but on simple inspection of the compositions of the principal components or factors, and their relations to correlations existing in the data-set.

Our experiment reveals that the most efficient methods are the Maximum-Likelihood factor analysis and the R-Mode principal components analysis, within which the varimax (orthogonal) rotations best reproduce correlations. Of these methods, maximum-likelihood factor analysis is considered the optimum method because of the greater simplicity of compositions. In addition to these methods, Kaiser's second generation "Little Jiffy" factor analysis was also found to be efficient. Three methods provide less sensitive reduction of the data: the "true" R-mode principal components analysis (without secondary rotations), the Q-mode principal components analysis, and the correspondence analysis.

In press: Marine Micropaleontology.

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PALEOCEANOGRAPHY

CARBON ISOTOPIC CHANGES IN BENTHIC FORAMINIFERA FROM THE WESTERN SOUTH ATLANTIC: RECONSTRUCTION OF GLACIAL ABYSSAL CIRCULATION PATTERNS

William B. Curry and George P. Lohmann

Oxygen and carbon isotopic analyses have been performed on the benthic foraminifera, *Planulina wuellerstorfi*, in

seven Late Quaternary piston cores from the Vema Channel-Rio Grande Rise region. The cores are distributed over the water depth interval 2340 m to 3939 m, which includes the present transition from North Atlantic Deep Water (NADW) to Antarctic Bottom Water (AABW).

The carbon isotopic records in the cores vary as a function of water depth. The shallowest and deepest cores show no significant glacial/interglacial difference in $\delta^{13}\text{C}$. The shallowest core has carbon isotopic composition of *P. wuellerstorfi* always greater than 0.40‰. The deepest core has carbon isotopic composition of *P. wuellerstorfi* always less than 0.4 ‰. Four of the five cores presently located in the NADW have benthic foraminiferal $\delta^{13}\text{C}$ that is significantly lower during glacial than interglacial isotopic stages. Comparison of average glacial and interglacial bathymetric profiles of $\delta^{13}\text{C}$ suggests that carbon isotopic changes in this region primarily reflect glacial/interglacial changes in abyssal circulation patterns or water mass geometry. We present three models to account for this: 1) vertical migration of the NADW-AABW transition to a depth shallower than 2.7 km during glacial isotopic stages; 2) transposition of NADW and CPDW during glacial isotopic stages; or 3) elimination of NADW during glacial isotopic stages. On the basis of paleontologic, isotopic and sedimentologic evidence, we consider elimination or reduction of glacial NADW the probable model.

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PALEOGENE PALEOCEANOGRAPHY: EARLY CENOZOIC OCEANS REVISITED

Bilal U. Haq

This paper is a review of the emerging unified view of the history of ocean circulation and climates during the Paleogene (65-24 Ma) based on evidence from many disciplines. Major threshold events at the Cretaceous/Tertiary boundary (65 Ma), in the latest Paleocene-early Eocene (53-49 Ma) and near the Eocene/Oligocene boundary (38 Ma), that profoundly effected the oceanographic/climatic history of the world ocean, are reviewed with special emphasis. Inferred global surface circulation maps are presented on paleogeographic reconstructions of the early Paleocene, middle Eocene and late Oligocene intervals.

The Paleogene was characterized by cooling high latitude temperatures and the

development of greater latitudinal thermal contrast that eventually led to the predominantly glacial mode of the Neogene. According to one model, during the Paleogene, the mode of deep water formation changed from predominantly in the low and mid latitudinal marginal seas, producing warm saline bottom water that was characteristic of the late Cretaceous, to predominantly in the high latitudinal areas, producing cold dense bottom water, characteristic of the present time.

Paleogene planktonic biogeographic data (shifts of assemblages through latitudes) and oxygen-isotopic data show cooling events in middle Paleocene, middle Eocene and near the Eocene/Oligocene boundary, and a major warming event that culminated in peak warming during the early Eocene. Biogeographic data show additional cooling events in the earliest Paleocene and middle Oligocene, and a warming event in the later middle Eocene. Plankton migrations data indicate that the middle Oligocene cooling episode may have been as severe as that near the Eocene/Oligocene boundary.

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P A L E O M A G N E T I C S

REMAGNETIZATION OF THE EOCENE OCEANIC FORMATION ON BARBADOS, WEST INDIES

Anna C. Shaughnessy and Charles R. Denham

The outcrop of the pelagic Middle-to-Upper Eocene Oceanic Formation on Barbados was remagnetized after it was uplifted and folded into its present position on Barbados. No polarity reversals were observed among the 274 samples from five sections at Gays Cove and one section at Bath. In their current structural attitude, the cleaned remanence directions are more tightly clustered than they would be if corrections to a horizontal bedding orientation were made. They also are more closely aligned with the Present and Geocentric Axial Dipole Fields in this position. The weak moderately stable magnetization is due in part to a brown stain originating from subareal weathering of the numerous intercalated volcanic ashes. The Oceanic Formation at its outcrop no longer bears the original Middle-to-Upper Eocene magnetic polarity stratigraphy.

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PALEONTOLOGY

CORRELATION OF ATLANTIC MEDITERRANEAN
AND INDO-PACIFIC NEOGENE STRATIGRAPHIES:
GEOCHRONOLOGY AND CHRONOSTRATIGRAPHY

William A. Berggren

The Neogene includes the Miocene ($T=23.2-5.4\text{Ma}$), Pliocene ($T=5.4-1.7\text{Ma}$) and Pleistocene ($T=1.7-0\text{Ma}$) epochs. A revised Neogene time scale is presented based upon a review and integration of recent data in the fields of biostratigraphy, magnetostratigraphy and radiochronology. Of the various magneto-biochronologies currently in vogue, that of Ryan *et al.* (1974) is found to be most consistent with biostratigraphically controlled radiochronology. At the same time the correlation of radiolarian biostratigraphy to core magnetostratigraphy by Theyer and Hammond (1979a,b; Theyer *et al.* 1978) has been used as a standard for correlation and calibration and results in some minor, but important, revisions to the chronostratigraphic chronology. The resulting "magnetobiochronologic" scale does not differ significantly, however, from those previously proposed by some authors (Ryan *et al.* 1974; Berggren and Van Couvering, 1974; Van Couvering and Berggren, 1977).

The revised Neogene time scale provides a chronologic framework for regional chronostratigraphic correlation of the standard Mediterranean Neogene Age/Stage sequence with those developed in geographically nearby (Parathethy) and distant (Indo-Pacific, West Coast North America) regions.

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Datum Plains (Osaka, Japan, Nov.
1981).

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CENOZOIC MARINE ENVIRONMENTS IN THE NORTH
ATLANTIC AND NORWEGIAN-GREENLAND SEA

William A. Berggren and Detmar Schnitker

A warm ocean with an abundant and diverse flora and fauna invaded the newly forming branches of the North Atlantic, first the Labrador Sea (Late Cretaceous), and then, beginning with the Eocene, the northeastern North Atlantic. Land and marine biotas at high latitudes indicate equable climates and low Paleogene latitudinal thermal gradients. The Greenland-Scotland Ridge, forming along

with the opening ocean, may have acted as an oceanic barrier, but not as an impenetrable hindrance to surface exchange of flora and fauna. Rising rates of biogenic silica deposition during the Eocene suggest high fertility, and thus, upwelling. The global Eocene/Oligocene cooling impoverished North Atlantic planktonic floras and faunas, while the deep water environment was drastically changed, both qualitatively and dynamically. Extinctions, speciations and fundamental depth and abundance readjustments of deep water benthic faunas bear witness to the physicochemical and structural changes of the deep hydrosphere; unconformities and a change in the sedimentation regime suggest a marked intensification of deep currents. It is uncertain whether these events are related to the onset of North Atlantic bottom water formation. Calcareous oozes on Voring Plateau indicate that substantial influx of North Atlantic surface water into the Norwegian Sea occurred during the middle and late Oligocene, following the opening of a seaway to the Arctic. An early Miocene warming trend was interrupted at the beginning of middle Miocene, expressed in the establishment of cool and temperate microfaunas and floras, as well as in oxygen isotope ratios. A dramatic drop in North Atlantic biological productivity, a change in the style of sedimentation (drift deposits), and the appearance of carbon-isotopically young water coincides with an inferred subsidence of the Iceland-Faeroe Ridge in the middle Miocene. Initiation of cold water reflux across the ridge was probably the last principal event towards the establishment of the modern global deep water circulation; the benthic microfaunas assumed their present day aspects through a major taxonomic turnover during the middle Miocene.

In press: Symposium: NATO Advance
Research Institute, Bressanone,
Italy, May 11-15, 1982.

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of Oil Companies.

CARBON AND OXYGEN ISOTOPIC DISEQUILIBRIA
OF RECENT DEEP-SEA BENTHIC FORAMINIFERADavid W. Graham, Bruce H. Corliss,
Michael L. Bender and
Lloyd D. Keigwin, Jr.

The carbon and oxygen isotopic compositions of 149 samples of benthic foraminifera from deep sea core tops indicate that none of the nine species studied secrete carbonate in isotopic equilibrium with ambient bottom water.

Uvigerina, *P. murrhina*, and *O. tener* are the closest to ^{18}O equilibrium (with average deviations about -0.4‰), while *P. wuellerstorfi* and *P. murrhina* are the closest to ^{13}C equilibrium (with average deviations about -10‰). *P. wuellerstorfi* shows the most systematic $\delta^{13}\text{C}$ -bottom water AOU relationship. The intra-specific variabilities in $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ suggest that estimates of paleo-temperatures can be made to a precision of $\pm 0.7^\circ\text{C}$, while estimates of past AOU can be made to $\pm 35\text{ }\mu\text{mol/kg}$. Based on intraspecific comparisons of the Recent samples with fossils, no temporal changes in the degree of either ^{18}O or ^{13}C disequilibrium have been detected for *P. wuellerstorfi*, *Uvigerina*, *O. tener*, or *G. subglobosa*.

In press: Marine Micropaleontology.

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SEARCH FOR MARKER EVENTS AT THE PALEOGENE-NEOGENE BOUNDARY

Bilal U. Haq

Many stratigraphic boundaries are related to cycles of sedimentation, which are in turn related to global changes in sea level. Thus most boundaries were conveniently picked where lithologic breaks were most obvious, either representing unconformities or sharp stratigraphic changes related to relatively rapid changes in the oceanographic/climatic regimes. This paper explores the stratigraphic record of the latest Oligocene and earliest Miocene interval for important marker event (events that have left behind widespread and easily retrievable record) that can be used as clues for picking the Paleogene-Neogene boundary in a potential strato-type section. Special emphasis is paid to the deep sea record as mandated by the IUGS Sub-commission on Paleogene Stratigraphy.

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POTENTIAL OF CALCAREOUS NANNOPLANKTON IN PALEOENVIRONMENTAL INTERPRETATIONS - A CASE STUDY OF THE MIOCENE OF THE ATLANTIC OCEAN

Bilal U. Haq and Bjorn A. Malmgren

The usefulness of calcareous nannoplankton paleobiogeographic data in paleoenvironmental interpretations is illustrated by a study from the Miocene of

the Atlantic Ocean. A summary of the statistical procedures and various ordination techniques used in reducing the complex paleobiogeographic data-sets, is followed by a discussion of the relative effectiveness of the various techniques to extract optimal environmental information from the data. The maximum-likelihood factor analysis and R-mode principal components analysis are considered to be most efficient.

A summary of the Paleogene and Miocene nannofossil biogeographic patterns is also presented. The application of an optimal 4-factor maximum-likelihood solution to the Atlantic Miocene nannofossils reveals patterns related to: i) temporal biogeographic evolution, ii) climatic variations, iii) spread of high latitude water-mass influences in times of climatic deterioration, and iv) regional variations in the biogeography of the South Atlantic in response to local factors. It is demonstrated that temperature-sensitive assemblages, such as the Discoaster-Sphenolithus assemblage, can be effectively used in the reconstruction of paleoclimate, if dissolution bias in the data is minimized during data-census. The Miocene paleoclimatic results of this study show a close correspondence to oxygen-isotopic paleoclimatic conclusions in published studies.

In press: Special Volume of Stockholm
Contributions in Geology Honoring
Prof. Ivar Hessland.

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BIOCHRONOLOGY - BIOLOGIC EVENTS IN TIME RESOLUTION

Bilal U. Haq and Thomas R. Worsley

Biochronology utilizes the irreversible process of organic evolution to order the sequence of "events" that help in the subdivision of geologic time and the documentation of earth history. This aspect of geochronology exploits the sequence of biostratigraphic events (usually the first and last appearances of taxa in continuous sedimentary sequences) and their inferred (or interpolated) ages to arrive at a utilitarian chronology. Biochronology thus goes one step further than biostratigraphy which only aims at recognizing fossil features that uniquely characterize a known stratigraphic level in a sedimentary section, without inherent chronologic significance. This essay is a philosophical discussion of the basic problems inherent in the practice of biochronology and a brief review of the state of the art of planktonic

biochronology, as well as its potential and limitations for wide geographical correlations.

In press: Special volume, "Absolute Chronology in Stratigraphy", J. Wiley, Publisher.

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ABYSSAL TELECONNECTIONS: INTERACTIVE DYNAMICS OF THE DEEP OCEAN CIRCULATION

David A. Johnson

A teleconnective linkage between two abyssal water masses consists of one or more zones of interaction, arranged sequentially in space and time. The properties, spatial extent, and advective nature of one of these water masses are directly attributable to the presence of the other via the zones of interaction. The sequence of components in the linkage may in some instances be configured linearly and respond in an irreversible fashion. In other instances the linkage is not unidirectional, but may include one or more feedback "loops" representing the dependence of each water mass upon the properties and extent of the other. Three types of water mass interaction are represented in the modern oceans; these are designated as: (1) reinforcing, (2) lateral blocking/re-direction, and (3) wedging. The criteria for discriminating between these types are geometrical, yet the physical processes and rates of interaction may be distinguishable between, and perhaps characteristic of, these different configurations.

Regions of water mass interaction are relatively broad, and are marked by sharp gradients of numerous water column properties; yet each of these gradients may be spatially restricted to a narrow interval of the overall mixing zone. Sediment characteristics exhibit a similar pattern; there is a broad zone of transition for several geological indices, yet the individual gradients are spatially restricted to a relatively narrow interval. Geological indices are of several types, including those which are integrative of multiple layers of the overlying water column, and those which reflect principally the near bottom water. Of the latter group, one must distinguish between those which reflect water properties and those which reflect water column advection, and avoid inferring one type of water characteristic on the basis of geological indices which are inappropriate for identifying such characteristics.

It is not possible to specify a priori all of the components of a teleconnection linkage. We can identify critical zones of interaction, and search for evidence of "threshold events" which contributed to the initiation or the breaking of a particular linkage. In order to establish the spatial and temporal sequence of components in a complex linkage, we must identify the frequency response and phase response spectra in high-resolution time series of appropriate paleoceanographic indices at key locations. We may identify future target areas for paleoceanographic drilling objectives by transforming the coordinate system for displaying existing results and selecting an orientation which is normal to the particular oceanographic gradient of interest.

In press: Paleogeography,
Paleoclimatology, Paleoecology.

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CRETACEOUS OCEAN FLOOR IN THE AMIRANTE PASSAGE: TECTONIC AND OCEANOGRAPHIC IMPLICATIONS

David A. Johnson, William A. Berggren
and J.E. Damuth

Core V34-76, obtained near the summit of a basement ridge in the axis of the Amirante Passage, recovered in situ pelagic chalk of latest Cretaceous age (*Abathomphalus mayaroensis* Zone, ca 66 Ma). This minimal age for the NNE-trending basement ridges places important constraints on the tectonic development of the western Indian Ocean, and confirms that the Amirante Passage has provided a deep-water connection between the Mascarene and Somali Basins throughout the entire Cenozoic.

In press: Marine Geology.

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RADIOLARIAN BIOGEOGRAPHY IN SURFACE SEDIMENTS OF THE EASTERN INDIAN OCEAN

David A. Johnson and C. Nigrini

We analyzed recurrent groups of radiolaria in 74 core top samples from a transect through the eastern Indian Ocean in order to supplement our previous results from the western Indian Ocean (Johnson and Nigrini, 1980). We now identify six distinct recurrent groups and nine radiolarian assemblages in the combined data set of 120 samples; this extended sample coverage has led to several reinterpretations of the oceanographic significance of the radiolarian

distribution patterns. Assemblage boundaries closely reflect the presence of distribution patterns. Assemblage boundaries closely reflect the presence of major oceanographic fronts and surface currents including the South Equatorial Divergence, Subtropical Gyre, Subtropical Convergence and Antarctic Convergence. At least four major aspects of the assemblages in the eastern transect are notably different from those in the western transect, leading to a marked east-west asymmetry in faunal distribution patterns across the Indian Ocean. The assemblage formerly associated with strong upwelling near the Arabian peninsula is present throughout the Bay of Bengal as well, and is interpreted to reflect high-salinity and low oxygen in the subsurface waters of the Indian Ocean north of the equator. A new assemblage has been identified associated with the westward-flowing Pacific water into the eastern Indian Ocean in low latitudes, and may be a potential stratigraphic and paleoclimatic marker for times of low sea level when this westward near-surface flow was shut off (i.e., glacial maxima). An extensive region in the core of the subtropical gyre between 25°S and 35°S is relatively barren of radiolaria, yet is marked by a characteristic assemblage distributed asymmetrically, perhaps reflecting the lack of a strong boundary current off the west coast of Australia. Assemblage boundaries in the vicinity of the eastward circumpolar flow are not strictly zonal, and may indicate significant deviations from the mean eastward flow as a necessary condition for conservation of potential vorticity when the flow encounters topographic irregularities.

In press: Marine Micropaleontology.

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NEOGENE PLANKTONIC FORAMINIFERA FROM DSDP SITES 502 AND 503

Lloyd D. Keigwin, Jr.

DSDP Sites 502 (Colombian Basin, western Atlantic Ocean) and 503 (eastern equatorial Pacific Ocean) are well-located to compare the Late Neogene paleoceanographic history of the tropical Atlantic and Pacific Oceans. Comparing the faunal and floral history at each location should reveal changes due to the Late Neogene shoaling of the Isthmus of Panama and the separation of the tropical Atlantic and Pacific Oceans.

At each site we recovered an apparently continuous, largely undisturbed sedimentary sequence from Holocene to about 8 million

years in age. Tropical and subtropical planktonic foraminifera are present throughout each sequence although diversity is lower and the preservation is poorer in the Pacific. At each location the Miocene/Pliocene boundary is defined by the first appearance of Globorotalia tumida, the Early-Late Pliocene boundary is defined by the extinction of Sphaeroidinellopsis, and the Pliocene-Pleistocene boundary is defined by the first appearance of Globorotalia truncatulinoides.

Planktonic foraminiferal assemblages at Sites 502 and 503 are generally similar until the Early Pliocene when the faunal histories diverge. Two important exceptions are the delayed first occurrence of Pulleniatina in the Atlantic (4.4 Ma) relative to the Pacific site (5.5. Ma) and the common presence of sinistral Neogloboquadrina acostaensis and sinistral Neogloboquadrina pachyderma in the Atlantic site. Sinistral M. acostaensis is rare in the Pacific site and sinistral N. pachyderma is absent entirely. The significance of sinistral N. pachyderma at Site 502 is unclear but it probably does not reflect cold water temperatures because of its association with an otherwise tropical-subtropical fauna.

As noted by other workers, the first planktonic foraminiferal evidence for increasing Atlantic-Pacific provinciality occurs in the Early Pliocene at 4 Ma with the appearance of Pulleniatina spectabilis in the Pacific and its exclusion from the Atlantic. Subsequent to that, Pullenitina disappeared from the Atlantic (3.3. Ma) and did not reappear until about 2.1 Ma, whereas it ranged continuously in the Pacific. The strongest planktonic foraminiferal biogeographic evidence for the separation of the two tropical oceans by the Panama Isthmus has been the development of an endemic lineage of Globorotalia in the Atlantic. Members of this group became numerically important in the Late Pliocene and give tropical Atlantic faunas of that age a distinctive appearance. Until recently the more advanced members of this lineage have not been recorded from Pacific sediments. At DSDP 503 the distinctive species Globorotalia pertenuis first appears at 3.3 Ma. The short range of this species in the Pacific and the complete absence of Globorotalia miocenica is further evidence that by about 3 Ma the emergent Panama Isthmus was an effective barrier to the exchange of tropical Atlantic and Pacific surface waters.

In press: DSDP Initial Reports, 68.

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GEOLOGICAL EFFECTS OF THE GULF STREAM ON THE NORTHERN BERMUDA RISE

Edward P. Laine and Charles D. Hollister

The Gulf Stream System contains a clockwise rotating set of bottom currents which influence the sea bed in the northern North American Basin. It is possible to interpret the present-day and historical record of current activity in this basin in terms of the deep flow of the Gulf Stream. This interpretation provides a much more satisfactory and consistent explanation of the geological record than previous interpretations based strictly on the influence of the classical abyssal circulation. The present-day circulation of the Gulf Stream actively resuspends large quantities of sediment on and near the northern Bermuda Rise, and it is suggested that this resuspension may be due to the eddy field which is embedded in the westward flowing return flow. During the late Cenozoic the Gulf Stream System was responsible for depositing and shaping the major acoustic/sedimentological units on the relatively smooth surface of the Horizon A complex. Fine-grained montmorillonite-rich sediments derived from the chemically weathered saprolites of the Hudson and St. Lawrence drainage basins were injected into the deep ocean basins by turbidity currents during the late Paleogene and the Neogene. Fine-grained turbidites from the St. Lawrence spread southward down the southeastern Sohms Abyssal Plain across the eastward-flowing Gulf Stream and its westward flowing return flows. Portions of these fine-grained sediments were entrained by the main and return flows and deposited downstream as acoustically non-laminated accumulations on the Corner and Bermuda Rises, respectively. The Hudson River input was injected into the deep basin through the Hudson Canyon System. The interaction of these fine-grained turbidites with the northward flowing deep flow of the Gulf Stream System led to the formation of the Gulf Stream Outer Ridge, here defined for the first time. During the late Neogene or early Pleistocene the Gulf Stream Outer Ridge was partially eroded by the Gulf Stream System and portions subsequently covered by coarse-grained Pleistocene turbidites. The coarse-grained illite-rich turbidites that flowed across the southeastern Sohms Abyssal Plain also crossed the main and return flows of the Gulf Stream System. The finer portions of these sediments were entrained and deposited as Pleistocene acoustically laminated sediments on the plateaus of the Bermuda and Corner Rises.

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277-310.

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C-0262, NR 083-004.

A CORRELATION BETWEEN THE DISTRIBUTION OF Uvigerina Peregrina Cushman AND ITS SEDIMENTARY SUBSTRATE

Kenneth G. Miller and George P. Lohmann

Uvigerina peregrina dominates the benthic foraminiferal fauna in water depths between 1000 and 2500 m on the continental margin southeast of Cape Cod. Previous workers have used this species either as an indicator of bathyal water depths, deepwater paleotemperatures between 3-4°C, or water of low oxygen content. Our study finds that correlations between abundances of U. peregrina and depth or water temperature are not maintained over wide areas, and that on the continental slope U. peregrina is not associated with water of low oxygen content. Instead, we find that the highest abundances of U. peregrina closely coincide with peak organic carbon and silt contents of continental slope sediments. This is strong evidence that, at least locally, the distribution of U. peregrina can be controlled by the character of its sediment substrate, rather than by the character of the overlying water.

In press: Bull. Geol. Soc. Amer.

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MAJOR CHANGE IN ATLANTIC DEEP AND BOTTOM WATERS 700,000 YEARS AGO: BENTHONIC FORA- MINIFERAL EVIDENCE FROM THE SOUTH ATLANTIC L.C. Peterson and G.P. Lohmann

In the modern South Atlantic the transition between deep water and bottom water is marked by a clear change in the associated benthonic foraminiferal fauna. Uvigerina and Globocassidulina characterize oxygen-poor Circumpolar Deep Water which has long been isolated from the surface. Planulina and miliolids are found associated with the more newly-formed, oxygen-rich North Atlantic Deep Water. Antarctic Bottom Water is characterized by "Epistominella" umbonifera.

Analysis of the benthonic foraminiferal faunas in two sediment cores recovered from the Vema and Hunter Channels in the western South Atlantic shows that the level of the transition between deep and bottom waters shallowed sharply about 700,000 years ago. This rise indicates a sharp, sustained

increase in the volume of bottom water flowing through the South Atlantic after this time. Prior to about 700,000 years ago, the amount of Antarctic Bottom Water entering the western South Atlantic was greatly reduced and Circumpolar Deep Water apparently accounted for the bulk of northward flow. Production of southward flowing North Atlantic Deep Water seems not to have been affected.

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17, 1982.

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THE TERMINAL EOCENE EVENT AND THE POLISH CONNECTION

J.A. Van Couvering, Marie-Pierre Aubry,
William A. Berggren, J.P. Bujak
and C.D. Naeser

The Eocene/Oligocene boundary in Europe is marked by major discontinuities in all environments: the "Grande Coupure" is continental mammals; the elimination of semi-tropical elements from high-latitude floras; the virtually complete replacement of the shallow-marine malacofauna; and an extraordinary downslope excursion of carbonate deposition in deep-ocean basins (drop in the CCD). These phenomena collectively represent the "Terminal Eocene Event" (TEE). In the Carpathian Mountains, the TEE is manifested in the thin but regionally persistent Globigerina Marl, a calcareous unit containing abundant cool-water microplankton that occurs within very thick, siliceous, bathyal flysch sequences. In southern Poland, the marl is of very latest Eocene age, within planktonic foraminifera zone P. 17, calcareous nannoplankton zone NP19/20, and the zone of the dinoflagellate *Rhombodinium perforatum*. Zircons from bentonites bracketing the marl are dated by fission-track analysis; at Polany, 2 underlying bentonites are 41.7 and 39.8 Ma, and at Znamirowice 2 overlying bentonites are 34.6 and 28.9 Ma, in sequence. This accords with glauconite K/Ar ages in western Europe by which the Eo/Oligocene boundary age is estimated at 37-38 Ma. Global correlations indicate that the TEE corresponds to a major glacio-eustatic regression with a duration of about 0.5 Ma, in which a large Antarctic ice cap was formed, the ocean circulation was permanently changed to the psychrospheric condition, and world climate shifted irreversibly towards the modern state.

In press: Paleogeography,
Palaeoecology, Palaeoclimatology.

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PETROLOGY

COMPOSITIONAL VARIATION IN NORMAL MORB FROM 22-24°N, MID-ATLANTIC RIDGE AND KANE FRACTURE ZONE

W.B. Bryan, Geoffrey Thompson
and J.N. Ludden

Basalts collected by dredging between 23°N and 25°N include samples from the active spreading ridges, median valley walls, and older walls of the Kane Fracture Zone transform fault at about 24°N. Chemical analyses of over 100 basalts and basalt glasses show the depletion in large-ion lithophile elements characteristic of "normal" ocean ridge basalts. Specifically, there is no evidence of special fracture-zone related alkalic volcanism, nor are there any significant differences between basalts from the median valley segments north and south of the fracture zone.

Petrogenesis of the basalts, as deduced from both petrographic and geochemical evidence, indicates that simple equilibrium crystallization accounts for a large part of the major element and trace element variation within discrete magma batches. However, more complex models are required to explain relations between samples showing large differences in large-ion lithophile element enrichments. A subset of samples of intermediate composition can be explained by simple mixing of highly fractionated basalt with new parental basalt. A number of high Al_2O_3 and high MgO samples may reflect accumulation and partial resorption of plagioclase and/or olivine. Mantle source inhomogeneity probably is not significant in producing variable large-ion-lithophile element enrichments. Variable degrees of partial melting probably do contribute to compositional heterogeneity, but specific models for such a process are not well-constrained by the data.

In press: Journal of Geophysical
Research.

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PETROLOGY OF TWO BACK-ARC BASINS OF THE NORTHERN PHILIPPINE SEA

Henry J. B. Dick

Basement rocks drilled in the Shikoku and Minami-Daito back-arc basins include sheet flows and pillow basalts but are predominantly sills and indicate extensive

off-axis volcanism. Although emplaced at similar water depths in or onto the ocean floor, the rocks from the two basins have very different chemistries.

The Shikoku Basin basalts lie within the composition range of abyssal tholeiites. They are atypical of MORB's in that they have somewhat sodic plagioclase, a slight enrichment in alkalis (lying parallel to rather than overlying the iron enrichment trend of abyssal tholeiites in the AFM diagram), and variable, often high primary water contents as indicated by vesicularity and mineralogy.

The Minami-Daito basement rocks consist of two interdigitated but unrelated series of alkaline and tholeiitic basalt sills. The alkaline series sills show a large range in composition related to post-intrusion settling of intratelluric olivine rather than in-situ crystal fractionation. The tholeiitic series consists of iron and titanium-rich basalts similar to those found at ocean islands, the Galapagos and Iceland. Despite the tremendous contrast in physiographic setting the Minami-Daito sill sequence resembles the intercalated tholeiitic and alkaline basalts which mark the transition from predominantly tholeiitic to alkaline volcanism in many Hawaiian volcanoes.

Both the Minami-Daito and Shikoku Basin basement rocks drilled during Leg 58 appear to have been emplaced contemporaneously with volcanic activity in an adjacent island-arc.

The origin of the Shikoku and Minami-Daito Basin basement rocks are related to remelting and contamination of the mantle by water-rich melt from subducted material beneath the basins. The large difference in chemistry of the igneous rocks drilled in the two basins is thought to reflect the influence on the process of magma segregation of old, relatively thick ocean lithosphere and the lack of a well defined spreading center in the Minami-Daito Basin, and a relatively thin lithosphere and well developed spreading center in the Shikoku Basin.

The greater depth of many back-arc basins compared to ocean crust of the same age (Sclater, 1972) is a likely consequence of hydrous remelting above a subduction zone of the relatively cool mantle beneath a terrain of old ocean crust and superimposed island-arc. The resulting mantle convection can be expected to produce a smaller topographic anomaly, and a deeper basin, than convection of the hotter mantle beneath major ocean ridges.

In press: American Journal of Science.

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EVIDENCE FOR HETEROGENEOUS PRIMARY MORB AND MANTLE SOURCES, NW INDIAN OCEAN

Fred A. Frey, John S. Dickey, Jr.,
Geoffrey Thompson, Wilfred B. Bryan
and Hugh L. Davies

Basalts from 5 Deep Sea Drilling Project (DSDP) sites in the northwest Indian Ocean (Somali Basin and Arabian Sea) have general geochemical features consistent with a spreading origin at the ancient Carlsberg Ridge. However, compared to most MORBS from other oceans they have low normative olivine, TiO_2 , Zr contents. There is no evidence that the mantle source of these northwest Indian Ocean basalts was enriched in incompatible elements relative to the Atlantic and Pacific ocean mantles. In detail, incompatible element abundances in these DSDP basalts establish that they evolved from several compositionally distinct parental magmas. In particular, basalts from site 236 in the Somali Basin have relatively high SiO_2 and low Na, P, Ti and Zr contents. These compositional features along with low normative olivine contents are similar to those proposed for melts derived by two-stage (or dynamic) melting. Published data also indicate there is no enrichment in incompatible elements at the southwest Indian Ocean triple junction, although southwest Indian Ocean basalts have slightly higher $^{87}\text{Sr}/^{86}\text{Sr}$ than "normal" Atlantic MORB. The data suggest that there are significant subtle geochemical variations in the Indian Ocean mantle sources, but are insufficient to show whether these variations have a systematic temporal or geographic distribution.

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PETROLOGY, GEOCHEMISTRY AND ORIGINAL TECTONIC SETTING OF BASALTS FROM THE MOZAMBIQUE BASIN AND RIDGE (DSDP SITES 248, 249 & 250), AND FROM THE SOUTHWEST INDIAN RIDGE (DSDP SITE 251)

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

Basalts from DSDP Sites 248, 249, 250 and 251 in the southwestern Indian Ocean formed in a complex tectonic region affected by the separation of Africa and South America. The different ages and

variable geochemical features of these DSDP basalts probably reflect this tectonic complexity. For example, site 251 on the flanks of the Southwest Indian Ridge is represented by normal MORB which probably originated at the Southwest Indian Ridge. Site 250 in the Mozambique Basin includes an older incompatible-element enriched unit which may represent basalt associated with the Prince Edward Fracture Zone; the upper unit is normal MORB. Basalts at Site 248 also in the Mozambique Basin are geochemically very unlike MORB and have strong continental affinities; they are also comparable in age to some of the continental Karroo basalts. They appear to be related to a subcontinental mantle source or to contamination by continental basement associated with the tectonic elevation of the Mozambique Ridge. Basalts from Site 249 on the Mozambique Ridge are relatively weathered but appear to be normal MORB. Their age, location, and composition are consistent with their origin at an early Cretaceous rift which has been postulated to have separated the Falkland Plateau from the Mozambique Ridge.

In press: Marine Geology.

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

INTRAGRANULAR MG-CALCITE COMMENT IN Halimeda PLATES FROM THE BRAZILIAN CONTINENTAL SHELF

E.T. Alexanderson and John D. Milliman

Many carbonate particles from the tropical Brazilian continental shelf contain impressive quantities of intragranular magnesian calcite cement, with 13 mole percent $MgCO_3$ (d (104) lattice spacing of 2.99 Å) in solid solution in the calcite. Cementation of aragonitic Halimeda plates occurs within the utricles; upon complete infilling, as much as 50 percent of the plates is composed of secondary magnesian calcite. Filling of these Halimeda plates by magnesian calcite plays a potentially important role in the preservation of the plates: mechanical removal of the primary aragonitic skeleton exposes the cemented utricles, resulting in thinner knobby plates with greater resistance to subsequent abrasion; moreover, retention of the calcite-filled utricles structures is enhanced during non-marine diagenesis. The wide distribution of intragranular cementation on the Brazilian shelf suggests that cementation by magnesian calcite may

account for a significant diagenetic flux of carbonate from seawater into sediments.

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HOLOCENE SEDIMENTATION OFF NAUSET INLET

David G. Aubrey, D.C. Twichell
and Stephanie L. Pfirman

Present conditions and sedimentary evolution of the shallow offshore region near Nauset Inlet on Cape Cod, Massachusetts, were clarified using high-resolution seismic-reflection profiles, sidescan-sonar records, and surface grab samples. The study area contains three provinces: 1) a nearshore province (shallower than 18 m) with a relatively steep slope (0.6°) and a cover of medium sand; 2) a northern offshore province covered with coarse sand, gravel and boulders, interpreted to be glacial drift, bordered to the south by a small valley; and 3) a southern offshore province with a gentle seaward-dipping slope (0.3°) and a surface sediment of coarse sand. The glacial drift exposed north of the east-trending valley can be traced southward under the coarse sand province on seismic-reflection profiles; the depression fill being comprised of either outwash sediment derived from the South Channel lobe at the east or Holocene aged marine sediments eroded from seacliffs to the north. Latest Holocene sediment supply to the study area appears to be limited to the zone shoreward of 18 m where the medium sand occurs. Present processes are actively reshaping the nearshore province, which is characterized by many east to northeast-trending shore-oblique channels that do not extend seaward of the 18-m contour. Coarse sand in the floors of these channels suggests they may be erosional features, and the presence of megaripples in the channel floors indicates present activity of these channels which are postulated to be formed by rip currents.

In press: Marine Geology.

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D-00102.

SEASONAL VARIATION IN THE FLUX OF ALGAL PIGMENTS TO A DEEP-WATER SITE IN THE PANAMA BASIN

Jonathan J. Cole, Susumu Honjo and
Nina Caraco

During 1979-1980 a moored array of time-series sediment traps was deployed at a station in the Panama Basin with traps set at 890, 2590 and 3560 m below the surface. At each depth the flux of algal pigments and organic carbon varied seasonally. Averaged over the year there were no significant differences in the quantities of these materials which arrived at the three depths, suggesting little dissolution or decomposition during settling in the deep part of the water column. The ratio of organic carbon:phaeopigment (mg:mg) had lowest values at 890 m (40:1) and greatest values (285:1) at 3560 m, but on the average showed no trend with depth. Although the flux of most of the carbonate and much of the organic C was associated with the sinking of coccolithophorids, the flux of algal pigments was not associated with coccoliths. The quantity of pigment sinking to deep water in the Panama Basin is roughly 50 to 100 times greater than the amount sinking to 2000 m at the Tongue of the Ocean and 10 to 70 times less than the amount sinking to 50 m at the Peru Upwelling.

Supported by: NSF Grant OCE80-25429.

THE GEOLOGY OF GUN SPALLS

Kenneth O. Emery

Analyses were made of thin-sections from gun spalls of French and of English origins collected at two 18th-century forts in the United States. The results show that the flint source material consists dominantly of quartz with minor amounts of calcite and organic matter from several organisms. Only trace quantities of clay and other minerals are present. The flints are Late Cretaceous (100 to 65 m.y.) in age. The French gun spall flint appears to be distinguishable from the English flint on the basis of coarser-grained matrix, less calcite, more abundant bryozoans and fewer foraminiferal tests. These differences in the quantities and associations of the constituents suggest that the French flints were deposited earlier and in an environment slightly shallower and nearer land than were the English flints, a conclusion that accords with the known depths and distributions of the seas in Europe during Late Cretaceous time.

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Colonial Frontier Guns: Chedron,
NB, The Fur Press, 150-153.

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IN SITU DISSOLUTION OF MONOSPECIFIC RADIOLARIAN ASSEMBLAGE IN THE CENTRAL NORTH PACIFIC WATERS

Jonathan Erez, Kozo Takahashi and
Susumu Honjo

A monospecific phaeodarian radiolarian assemblage of *Castanidium longispinum* was placed in plastic cages built with 245 μ m nylon mesh and exposed in *in situ* seawater at different depths for 61 days at the central North Pacific. This phaeodarian radiolarian species has one of the most porous skeletons among the radiolaria and weight losses were therefore very high. Above the thermocline weight losses were 60-90 percent, and below it 40 percent for the duration of the experiment. These weight losses are roughly an order of magnitude higher than those reported earlier (Berger, 1968). Kinetic considerations show that temperature is the major factor that controls silica dissolution rates in the ocean.

In press: Earth and Planetary
Science Letters.

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CLIMATIC ACME EVENTS IN THE SEA AND ON LAND

Bilal U. Haq

Major climatic events in the geologic past have left a variety of retrievable records in the sediments, both on land and sea. Some marked fluctuations in the climates are evident from widely distributed sedimentological, geochemical and paleontological features. This paper is mainly concerned with the paleontological record of widespread latitudinal domination of certain floral and faunal elements during times of extreme climatic change. Numerous intervals during which paleobiogeographic patterns show poleward extension of tropical assemblages, or equatorward extension of cold, higher latitude assemblages, have been documented for the Cenozoic. These events have been informally termed as climatic acme events (indicating peak climatic change) and have been used successfully in the reconstruction of the paleoclimate. The purpose of this paper is to describe and illustrate the concept of climatic acme events with

examples from the Cenozoic marine and terrestrial record, and where available, evidence from the oxygen-isotope record that corroborates the paleontological conclusions. The usefulness of acme events in biostratigraphic resolution of higher latitudes is also illustrated.

In press: Special Volume on Pre-Pleistocene Climates, Studies in Geophysics, National Research Council.

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EROSION AND DEPOSITION ON THE EASTERN MARGIN OF THE BERMUDA RISE IN THE LATE QUATERNARY

Charles D. Hollister
and Mary Jo Richardson

A near-bottom survey has been made on the Eastward Scarp (32° 50'N, 57° 30'W) of the Bermuda Rise, which rises 1150 m above the 5500 m deep Sohm Abyssal Plain in the western North Atlantic. The survey reveals evidence of erosion and deposition at present and in the late Quaternary by the deeper levels of the westward flowing Gulf Stream Return Flow. Four distinct regions of increasing bed gradient show increasing sediment smoothing and scour in the transition from plateau to abyssal plain.

Bedforms observed are current crescents, crag and tail, triangular ripples, elongate mounds, transverse mud ripples, lineations, and furrows ranging from 10 m to 1 m or less in depth, decreasing generally with bed gradient. Measured near bottom current speeds are up to 20 cms⁻¹. Temperature structure on the lower steep slopes suggests that detachment of bottom mixed layers may occur there.

At present, extensive net erosion appears to be confined to the lower steep slopes of the Scarp. Reflection profiles (4kHz) show that there has been erosion in areas thinly draped with recent sediments and in areas that show development of small scarps. The distribution of subsurface acoustic characteristics of the region corresponds broadly to the areas characterized by bed gradient and distinct sedimentation conditions. Subsurface hyperbolae, possibly caused by buried furrows, show furrow persistence through several tens of meters of deposition. Erosion occurs up to the top of the scarp during episodes of presumed stronger currents which may correspond with intensified circulation during glacials.

In press: Deep Sea Research.

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REMINERALIZATION AND ACCUMULATION OF MATERIALS IN DEEP SEA SEDIMENT

Susumu Honjo

The contents of particles settling through the oceanic water column are vastly different than those from the bottom sediment. This is essentially due to the remineralization of plankton-produced biogenic material in settling particles at the deep-sea floor. The proportion of refractory detritus particles, a minor constituent in the settling material, increases in bottom surface sediment. A simple model using mass flux of biogenic constituents and their proportions in settling particles and bottom sediment, relative mobilization and net accumulation rates of sedimentary components, can be constructed assuming conservation of refractory particles. At far off-shore oligotrophic deep ocean stations, biogenic constituents were highly mobilized with large recycling rates resulting in small accumulations of sediment. At a highly productive, near-shore deep ocean site, a large proportion of biogenic particles were retained in the bottom sediment which provided high accumulation rates for each biogenic constituent. The estimated net-sedimentation rates generally agreed with the values derived by other methods.

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and OCE79-25429.

SEASONALITY AND INTERACTION OF BIOGENIC AND LITHOGENIC PARTICULATE FLUX AT PANAMA BASIN

Susumu Honjo

A year-round, incremented sediment trap experiment at a deep Panama Basin station revealed that the mass flux was seasonally pulsed, immediately reflecting surface productivity. A prominent spike of carbonate was caused by a bloom of a single species of coccolithorophorid during the June-July increment. This bloom delivered approximately 30 grams of coccoliths to a square meter of 3860 m sea floor. Suspended particles, particularly smectite clay supplied from the nearby continental slope by advective transport, were scavenged and agglutinated by fast settling mucilage fragments produced by the coccolithophorids, thus providing a much larger flux at deeper water column levels.

Supported by: NSF Grant OCE81-25429.

MARINE SNOW ASSESSMENT: IN-SITU DIRECT OPTICAL MEASUREMENT OF MESOPELAGIC AGGREGATES IN THE OPEN OCEAN

Susumu Honjo, Kenneth W. Doherty and
Yogesh C. Agrawal

Macroscopic amorphous aggregates, or "marine snow", are more commonly found in the neritic open ocean in recent years. These aggregates are extremely fragile and are destroyed by plankton nets; the sparse and patchy distribution of these particles makes their sampling with a Niskin bottle impossible. In order to assess the size and spatial distribution of macroscopic aggregates throughout a deep water column we developed a photographic surveillance system which can be lowered to any depth. The system, based on the light scattering theory in water, uses a well collimated beam of light produced by high-powered strobe lights through a Fresnel lens focused downward at an angle of 45°. Illuminated aggregates in the beam of light are photographed from a direction perpendicular to the light axis. The aggregates within a volume of 106 x 156 x 40 cm are recorded as a photographic image. The image resolution is about 200 μ m. The instrument was deployed along a transect off California from the surface to 3521 m. More than 9500 individual photographs were taken. The abundance of macroscopic aggregates ranged from roughly 10 aggregates/liter near the surface to 2 aggregates/liter at depth.

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SEDIMENTATION OF BIOGENIC MATTER IN THE DEEP OCEAN

Susumu Honjo, Steven J. Manganini
and Jonathan Cole

The major constituents of biogenic particles which settle through the water column of the ocean are carbonate tests, opaline shells, and particulate organic matter (cellular and amorphous). This paper describes the quality and quantity of biogenic particle fluxes to the deep ocean and presents a comparison with biogenic remains in the bottom sediment. Studies of samples collected by PARFLUX sediment trap experiments in the Atlantic and Pacific oceans have shown that 60 to 90 percent of the total particulate flux is of biogenic origin; the contribution of biogenic materials decreases with increasing depth. Carbonate hard parts accounted for 30 to 60 percent of the biogenic flux and were the largest constituents in pelagic sediments at temperate and tropical areas. Combustible components ranged from 10 to 30 percent of the biogenic flux with

zooplankton remains and fecal pellets accounting for the bulk of the organic flux. Amorphous fine particles were also significant in the organic flux to the deep sea. The atomic ratio of organic constituents in settling particles deviated systematically from the "Redfield ratio" of 106:16:1 (C:N:P) for marine plankton. In the mesopelagic depths the ratio was 200:21:1, and in the bathypelagic depths the ratio was 300:33:1, with a wide range of variation in phosphorus.

The residence time of biogenic particles in the deep-ocean water column is relatively short and the particles are expected to arrive at the abyssal floor without major dissolution and remineralization (excepting small opal particles). Fine organic particles such as cell remains and pigmented granules are a major source of organic carbon and nitrogen at deep traps. Microscopic study suggests that those fine organic particles were once included in larger but loosely-formed settling particles that settled rapidly. Fine organic particles dispersed from settling fecal pellets or similar settling particles are reinjected into the water column resulting in "secondary" suspended particles. These particles are eventually remineralized during suspension. Based on our experiments the decomposition rate of organic C in the deep water was estimated to be about 2.2 mg C m⁻² day⁻¹. This rate is consistent with rates of oxygen consumption estimated by other investigators.

The bottom sediment is drastically different in composition (being strongly enriched by refractory lithogenic particles due to the remineralization of biogenic matter). A hypothetical benthic transition layer serves as a reservoir of benthic activity and can exist under certain conditions at the abyssal floor.

In press: Deep Sea Research.

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SEDIMENTATION OF LITHOGENIC PARTICLES IN THE DEEP OCEAN

Susumu Honjo, Steven J. Manganini and
Lawrence Poppe

Investigation of lithogenic particulates collected by sediment traps in open ocean stations revealed that the sediment flux increased linearly with depth in the water column. This rate of increase decreased with distance of the station from the continent; it was largest at the Panama Basin station and almost negligible at the

E. Hawaii Abyssal Plain station. At the Panama Basin station, smectite flux increased with depth. We suggest that smectite resuspended from bottom sediments of the continental slope west of the sediment trap station is advected by easterly deep currents, and the suspended particles are then possibly entrapped by large settling particles. On the other hand, the flux of hemipelagic clay particles, kaolinite and chlorite, was constant at all depths; this can be explained by incorporation of these particles in fecal pellets which then settle from the surface water. At the Demerara Abyssal Basin Station, flux of illite and chlorite particles increased with depth and the flux of smectite was constant. A sudden increase of the flux of illite and chlorite was observed near the bottom traps at the Sohm Abyssal Plain station. The flux of quartz and feldspar was 10 to 15 percent of the clay flux.

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DEEP ADVECTIVE TRANSPORT OF LITHOGENIC PARTICLES IN PANAMA BASIN

Susumu Honjo, Derek W. Spencer
and John W. Farrington

Sediment traps were deployed at several depths (660 to 3800 m) in the Panama Basin. The flux of lithogenic particles increased with increasing depth. This increase comprised, primarily, beidellite particles (a smectite clay) which were identical to the clay occurring in bottom sediment on the continental slope to the west of the sediment trap mooring. Beidellite vertical flux at the Panama Basin station increased when an easterly current prevailed, and decreased when the current reversed, indicating that a major portion of smectite was transported horizontally at mid-water depth to the mooring site from the nearby continental slope.

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083-004.

NEOGENE SEDIMENTATION AND EROSION IN THE AMIRANTE PASSAGE, WESTERN INDIAN OCEAN

David A. Johnson, M.T. Ledbetter and
J.E. Damuth

Twenty piston cores were obtained from the northern Mascarene Basin and Amirante Passage in order to determine the effects

of the flow of the deep western boundary current (DWBC) upon the lithologic and stratigraphic record of the late Cenozoic. The cores span a depth interval of 3350 to 5200 meters, which corresponds with the transition zone between high-salinity North Atlantic Deep Water (NADW)/Circumpolar Water (CPW) and the underlying low-salinity, high-oxygen Antarctic Bottom Water (AABW). Lithologic, paleomagnetic, and biostratigraphic analyses of the cores suggest that the modern abyssal flow regime and sediment distribution patterns are substantially different from those of the Pleistocene and of the middle Tertiary. During the late Cretaceous and for most of the Paleogene, pelagic sedimentation occurred in the passage region in the absence of significant bottom current activity. The DWBC was well developed by the early Miocene, transporting coarse detrital sands northward into the channel axes and ridge flanks of the Amirante Passage from the northern Mascarene Basin and the continental margin of Madagascar. The DWBC was confined to depths below ~4 Km until the Middle Miocene, at which time the flow strengthened and shallowed considerably, extending upward in the water column to <3300 m. Strong DWBC flow occupied the entire width of the passage below 3300 m at least intermittently during the entire Neogene, producing extensive erosion surfaces during the middle Miocene, the latest Miocene to Pliocene, and in the Pleistocene. Today the flow of the DWBC through the passage is relatively weak and notably asymmetrical with strong flow only below ~4000 m in the western channels. Relatively weak flow occurs in the eastern channels and in the Amirante Trench axis. The presence of extensive Pleistocene and late Tertiary erosion at intermediate depths (3-4 km) in the Indian Ocean is in sharp contrast to the depositional continuity at these same depths in the central and South Atlantic farther "upstream" in NADW. This contrast suggests that the initiation and fluctuations of circumpolar flow rather than the rate of production of NADW may have been the major controlling factor in the late Tertiary erosional history of the Amirante Passage.

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VARIATION IN THE CARBONATE REACTIVITY OF DEEP-SEA SEDIMENTS: DETERMINATION FROM FLUX EXPERIMENTS

Robin S. Keir

Using a stirred-flow reactor, alkalinity flux from sediment into overlying seawater was measured as a function

of dissolved carbonate ion concentration. Synthetic calcite powder and ten deep-sea sediment samplers ranging from 30% to 85% CaCO_3 content were employed in these experiments. In addition, a diffusion-dissolution model analogous to the experimental conditions was developed to interpret the results.

The experimental results depend on the total reactive surface area of calcite and aragonite in the sediment, which are characterized by apparent rate constants, k_c and k_a . The flux is found to be approximately proportional to

$$\text{Flux} \propto \frac{\sim \partial [\text{CO}_3^{=}]}{(\Sigma + 2A)} \left[\frac{k_c}{(n_c + 1)} \frac{(n_c + 1)}{S_c} + b \frac{k_a}{(n_a + 1)} \frac{(n_a + 1)}{S_a} \right]^{1/2}$$

where Σ and A are the total CO_2 and alkalinity of the overlying water, n_a and n_c are constants, b is the ratio of aragonite to calcite solubility. $S_{c,a} = 1 - [\text{Ca}^{2+}][\text{CO}_3^{=}] / K_{sp',c,a}$ and c, a refer to calcite or aragonite.

Variation of k_c and k_a between sediment samples shows the following:

- (1) The calcite reactive surface area is correlated with carbonate content between 0 and 60% CaCO_3 .
- (2) The aragonite reactive surface area diminishes by an order of magnitude as water depth increases below the aragonite compensation depth (ACD).
- (3) A remnant aragonite standing crop persists below the ACD in sediment with greater than 20% CaCO_3 . This may be due to mixing of the upper few centimeters by bioturbation which results in the escape of a small fraction of the settling aragonite from dissolution.

In this study, the measured apparent calcite rate constant for a carbonate rich sediment is two orders of magnitude lower than that determined from previous kinetic experiments on suspended sediment. Whether this is due to a diffusive boundary layer or other effects cannot be determined with certainty.

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STRUCTURAL CONTROL OF THE RESISTANCE OF PLANKTONIC FORAMINIFERA TO DISSOLUTION: THE ROLE OF ENCAPSULATED FINE GRAIN SEDIMENT

Robin S. Keir and David C. Hurd

The tests of planktonic foraminifera recovered from deep-sea sediment are commonly observed to encapsulate fine grain carbonate sediment within their chambers. In sediment below the lysocline, the interstitial water within the chambers may not be as corrosive as the seawater in contact with the outer surface of the test due to slow continuous dissolution of the encapsulated carbonate. As a consequence, the pore walls of the foram dissolve more slowly than the outer surface of the test.

Using published dissolution rate measurements for forams and deep-sea sediment, the effect of diffusional inhibition of pore wall dissolution was quantitatively estimated with a one-dimensional model for the steady state condition where diffusional flux across the mouth of the pores is balanced by the dissolution flux from the encapsulated fines and the pore walls. The diffusional effect is found to principally depend on the structural parametric ratio, $T_w d_T / f$, where T_w is the wall thickness, d_T the test diameter and f is the test porosity. In the case of adult forams, the ratio of the pore wall to outer surface dissolution flux was found to vary between 60 percent for the thin-walled porous species to 30 percent for thick-walled tests.

Incorporation of the predicted pore to outer surface flux ratios with the morphologic index equation of Adelseck (1978) results in a very good prediction (73 percent of the variation) of the solution index of Berger (1975) obtained from ranking species counts from core tops.

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LATE MIOCENE OCEANOGRAPHY OF THE PACIFIC RECORDED BY CALCAREOUS NANNOPLANKTON

George P. Lohmann and Jodell J. Carlson

An analysis of the variability in the composition and distribution of Pacific Late Miocene calcareous nannoplankton about their average biogeography shows that there are two environmental factors causing that variability. The first is climate and produces a latitudinal differentiation of the Late Miocene nannoflora. The second is selective dissolution and superimposes a bathymetric differentiation of the

nannoflora on that due to climate. These two factors together produce three distinct Late Miocene nannofloral assemblages. Reticulofenestra pseudobilica and Coccolithus pelagicus characterize a high-latitude assemblage. In low-latitudes there is a shallow-water, undissolved assemblage characterized by sphenoliths, small elliptical placoliths and Coccolithus pataecus and a deeper-water, dissolved assemblage characterized by discoasters and Cyclococcolithus leptoporus.

Most of the variation in the nannoplankton compositions at the 15 sites studied can be attributed to changes in climate; however, the overall character of nannoflora at a site is often entirely altered by dissolution. Selective dissolution tends to give Late Miocene nannofloral assemblages a cooler water aspect, and at the same time changes the composition of the warmer-water component towards more resistant taxa.

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EROSION AND DEPOSITION IN INTERPLAIN CHANNELS OF THE MAURY CHANNEL SYSTEM, NORTHEAST ATLANTIC

Peter S. Lonsdale, Charles D. Hollister
and Larry Mayer

Large turbidity currents originating on the insular margin of southern Iceland have flowed down a 2500 km-long pathway comprising rise valleys, fan valleys, unchanneled plains and segments of erosional and depositional deep-sea channels that are collectively called the Maury Channel system. Two steep interplain reaches of the channel have been cut up to 100 m through volcanogenic turbidites of probable Late Pleistocene age. Near-bottom observations with side-scan sonars and profilers across the upper channels (at 59°24'N, 18°50'W, 2750 m depth) defined their lower interplain channel (around 56°23'N, 24°25'W, 3340 m depth) and defined their structure and morphology. The upper channels, and a tributary to the lower channel, start as broad shallow depressions that deepen and narrow downstream. The lower channel has a pattern of anastomosing branches that probably evolved by headward extension of low-angle tributaries to the original sinuous channel, and its branches are at different stages of development. Several hundred stereo-pairs of bottom photographs portray excellent exposures of the

surprisingly well-indurated rocks on channel walls and floors, showing such flysch-like characteristics as cyclic graded bedding, clastic dikes, and syndepositional deformation. The lower-channel branches have been cut by turbidity currents with speeds of 5-12 m/sec, and combined discharges exceeding $1 \times 10^6 \text{ m}^3/\text{sec}$. Bedrock erosion in and around the channels has proceeded by intense corrosion and fluid stressing, and is marked by such small-scale effects as rock polishing, fluting, pot-holding and ledge recession. Rockfalls have caused retreat of steep channel walls, and conglomerate or pebbly mudstone deposits suggest that debris flows have been locally active. Some coarse debris delivered by these processes and "clay balls" torn from semi-lithified outcrops remain in the channels, but the channel fill is generally thin, with a patchy veneer of pelagic mud that has accumulated since the last major turbidity current event. The surfaces of the unconsolidated sediment have been smoothed and lineated, or moulded into scour moats and occasional fields of ripples, by thermohaline currents. These less energetic flows, diverted by the channel topography, have redistributed fine sediment both down and up the channel branches, mainly as suspended load in a bottom nepheloid layer rather than as bedload. Tidal currents, significant sediment-movers in many submarine canyons, were of negligible importance in this deep-sea channel.

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SEDIMENT TRANSPORT OVER THE HATTON AND GARDAR CONTOURITE DRIFTS

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

The contrasted modes of transport and deposition of sandy and muddy contourites have been examined by hydrographic, photographic, lithologic and seismic data from Hatton and Gardar sediment drifts in the East Reykjanes Basin, northeastern Atlantic Ocean. Gardar Drift is of muddy contourites deposited from Iceland-Scotland Overflow Water (ISOW) with a thick and relatively intense nepheloid layer whose particles originate from Iceland. Hatton drift is also mainly of mud, possibly from Rockall Bank, but at its foot a strong northeastward flowing boundary current moves winnowed foraminiferal sand as ripples and low sand waves. The nepheloid layer on Hatton is locally generated and is

mainly in a layer of North Atlantic Deep Water (NADW) contaminated with Antarctic Bottom Water (AABW). This layer with its associated particles spreads across the basin as far as the crest of Gardar Drift. The bottom mixed layer over Gardar is mainly thin (30-40 m) and, following the model of Weatherly and Martin (1978), indicative of depositional shear-stresses ($u_* < 0.7 \text{ cm s}^{-1}$). Currents are less than 12 cm s^{-1} . Currents are less than 12 cm s^{-1} . Where the currents are fast (maximum 23 cm s^{-1}) and $u_* > 0.85 \text{ cm s}^{-1}$ over sands at the foot of Hatton Drift the mixed layer is 89 cm thick, but this thins to less than 40 m higher up on the drift as the environment changes from winnowing towards deposition of more muddy contourites.

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LATE CRETACEOUS TO EARLY TERTIARY AGGLUTINATED BENTHIC FORAMINIFERA IN THE LABRADOR SEA

Kenneth G. Miller, Felix M. Gradstein
and William A. Berggren

Predominantly agglutinated deep-sea benthic foraminiferal assemblages from Cretaceous to Tertiary sediments have been identified from 30 DSDP sites from throughout the world ocean. Two types of assemblages are distinguishable by wall texture, test size, paleobathymetric and stratigraphic distribution, and generic and specific composition. Smooth-walled "type B" assemblages are restricted to the Cretaceous deep sea. Coarse-walled, late Cretaceous to Paleogene "type A" (= flysch type) assemblages consisting of larger-sized tests are found from bathyal to abyssal depths in the deep sea, Labrador Shelf, East Newfoundland Shelf, North Sea, and European flysch basins.

We compared agglutinated assemblages found in the Eocene of the deep Labrador Sea (DSDP Site 112) with Maestrichtian to Eocene assemblages of the Canadian margin (Labrador and East Newfoundland Shelves). In addition, we compared the ranges of agglutinated taxa from this region with previously reported ranges from the North Sea, European flysch basins, and the deep sea. Both coeval and diachronous stratigraphic ranges were noted. Despite diachrony of certain taxa, agglutinated foraminifera appear to be at least locally useful in the zonation of Labrador Sea sediments.

A major faunal turnover occurs in the Labrador Sea at the end of the Eocene. An Eocene type A agglutinated assemblage is replaced in Site 112 by an Oligocene calcareous benthic foraminiferal assemblage. A similar terminal Eocene exit of agglutinated assemblages occurs in most Canadian margin and North Sea wells. In contrast to the Canadian margin where the agglutinated assemblages are associated with shales of high organic carbon content, lithology and percent organic carbon are relatively constant across the faunal change in Site 112. Thus, at least in the deep-sea, high organic carbon may not be a prerequisite to the development of predominantly agglutinated assemblages. In addition, the association of the agglutinated assemblages with sediments high in calcium carbonate does not support previous suggestions of deposition below the CCD as a requirement of flysch-type assemblages.

We suggest that the replacement of agglutinated assemblages in the deep Labrador Sea by calcareous assemblages was due to a change in hydrographic properties associated with the evolution of the psychrosphere. Sedimentological evidence from this region indicated initiation of northern sources of bottom water in the late Eocene to early Oligocene which may be related to the exit of agglutinated foraminifera. This resulted in the influx of higher oxygen bottom waters and a lowering of the CCD which may have favored the replacement of agglutinated assemblages by calcareous assemblages.

In press: Micropaleontology.

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DEPOSITIONAL PATTERNS OF MODERN ORINOCO/ AMAZON MUDS ON THE NORTHERN VENEZUELAN SHELF

John D. Milliman, Jorge Butenko,
Jean Paul Barbot and Jan Hedberg

Modern muds derived from the Orinoco and Amazon Rivers are gradually covering early-Holocene (shallow-water) reefs and sands on the continental shelf and upper slope north of the Paris peninsula. Throughout much of the area the muds are more or less continuous and locally as thick as 20 m. In other places the muds form an undulating topography (with lows consisting of underlying outcrops of relict sands/reefs) that appears to be migrating westward. Sediment accumulation apparently began after the opening of the Gulf of Paria about 10,000 years ago, and is continuing at present, due to the north and

westward drift of the Equatorial Current. The undulating topography is attributed to non-deposition or erosion around locally exposed irregular hard grounds rather than formation of a mud-wave type of bedform.

In press: Journal of Marine Research.

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CHARACTER AND DIAGENESIS OF ARCTIC CARBONATE BEACH SANDS

John D. Milliman and Ann M. Petricca

Carbonate sands from pocket beaches north of Tromsø, Norway, resemble algal maerl sediments from mid and low latitudes. As a result, the mineralogy of these Arctic carbonates is dominated by magnesian calcite (10 to 12 mole percent $MgCO_3$), with far smaller amounts of aragonite and calcite. Microscopic study shows abundant evidence for degradation (dissolution) of the particles, although some precipitation (biogenic) of internal cements can occur in living algal nodules.

In press: Sedimentology.

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THE ROLE OF TRANSPORT PROCESS IN DETERMINING THE SOLUBILITY BEHAVIOR OF CALCITE AND ARAGONITE IN THE DEEP SEA

John W. Morse, Susumu Honjo and Alfonso Mucci

The relationship between the accumulation of biogenically derived calcite and aragonite in deep sea sediments, and the chemistry of the seawater overlying these sediments has been intensely studied in recent years. In most cases, it has been assumed that calcite and aragonite have unique solubilities which are a function of temperature, pressure and salinity. However, experimental measurements of calcite and aragonite solubility in seawater have yielded results which are distinctly different from those predicted based on thermodynamic considerations for pure phases. This coupled with clear evidence that surface phases form which differ in composition from those of the pure "bulk" solids indicates that surface history can significantly influence solubility behavior. In the Northwest Atlantic Ocean the difference in the depths at which the saturation level is calculated, based on experimentally measured and thermodynamically derived solubilities, is approximately 1500 m for both calcite and aragonite.

Because surface history is important to solubility behavior it is necessary to understand the processes which take place during the transformation of a biogenic calcium carbonate from part of a living organism to a component of a deep-sea sediment. Most deep-sea sediment aragonite is derived from the shells of pteropods and heteropods. It appears that organic material is removed from these shells rapidly after the death of the organism. The fact that these relatively large carbonate particles have high sinking velocities and that the aragonite solubility-controlling surface phase forms slowly indicates that their solubility behavior should more closely follow the thermodynamically predicted behavior than apparent solubilities found in long term equilibration experiments. This hypothesis is consistent with observations of the distribution of biogenic aragonite in sediments near Bermuda. The dominant sources of the calcite component of deep-sea sediments are foraminifera tests and coccoliths. The foraminifera tests also appear to lose their organic matter relatively quickly and have intermediate sinking velocities. It has been observed that surface phases which control calcite solubility can form quickly from super-saturated waters found in the upper regions of the open ocean. This indicates that their solubility behavior should closely follow that found in seawater equilibration experiments. This hypothesis is consistent with the general relation found between the depth at which dissolution of foraminifera tests become evident and the saturation depth calculated from apparent solubility measurements. The behavior of coccoliths is very complex due to the fact that biological transport processes (e.g. in fecal pellets) and reprocessing in sediments play a major role in controlling their surface history.

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DEPARTMENT OF OCEAN ENGINEERING
Earl E. Hays, Department Chairman

OCEAN ENGINEERING

A C O U S T I C S

FLUCTUATIONS IN SOUND TRANSMISSION
THROUGH INTERNAL WAVES ASSOCIATED WITH
THE THERMOCLINE: A COMPUTER MODEL FOR
ACOUSTIC TRANSMISSION THROUGH SOUND
VELOCITY FIELDS CALCULATED FROM
THERMISTOR CHAIN, CTD, XBT AND
ACOUSTIC BACKSCATTERING

Lincoln Baxter II and Marshall H. Orr

Data sets obtained from towed thermistor strings, instrumented tow bodies, conductivity temperature depth sensors, expendable bathythermographs, sound velocimeters and high frequency acoustic backscattering systems provide detailed information on the temporal and spatial variability of the sound velocity field in the upper ocean. The data sets show that internal waves and other small scale fluid phenomena such as instabilities can significantly perturb the sound velocity field and consequently sound propagation. Little attention has been focused on the magnitude of short range, high frequency acoustic propagation variability caused by internal wave field and/or water mass variability. A ray trace program package has been developed which numerically integrates with a fourth order Runge-Kutta method the time dependent eikonal equations through a range dependent sound velocity field. The sound speed profiles, which are calculated from field data, are entered into a matrix with sizes larger than the numerical integration steps. Consequently the profiles are interpolated between matrix steps with the bicubic interpolation technique of Akima. Calculations for sound speed fields perturbed by internal waves show that at a fixed position the intensity of the sound intensity field can vary by as much as 20 dB as a function of time.

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WHOI Contribution No. 5031.

SOUND CHANNEL PROPAGATION THROUGH EDDIES
SOUTHEAST OF THE GULF STREAM

J.C. Beckerle, L. Baxter, R.P. Porter
and R.C. Spindel

Acoustical signals at 270 Hz from SOFAR floats drifting in the region southeast of the Gulf Stream were recorded during most of 1975 from a near axis sound channel

hydrophone near Bermuda. The amplitude levels received exhibit a large increase (12-18 dB) commencing about 24 July, following a long period (March to July) of relatively lower peak level amplitudes. A major part of the increase can be attributed to the influence of a large cyclonic eddy (Gulf Stream ring) that passed slowly between the SOFAR floats and Bermuda. Such an eddy produces a large sound speed anomaly that extends to depths below the axis of the sound channel. On 24 July, two SOFAR floats were known to have approximately the same sound transmission path through the edge of the large eddy. The sound transmission peaks occur when no ocean eddy is between the SOFAR floats and the receiver. Their spacing shows they occur at regular refraction caustics in the sound channel. When the sound transmission path passes through an eddy, these transmission focal distances are shifted to greater range and the signal level may be greatly enhanced. The decrease of caustic peak intensities with range is 5 dB per double distance, and this agrees with theory. Several different levels of peak acoustic intensity occur and these result from two float depths and oceanic thermocline oscillations.

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WHOI Contribution No. 4333.

ANGLE-INDEPENDENT DOPPLER
VELOCITY MEASUREMENT

Nadav Levanon and Ehud Weinstein

The well-known relation between the radar Doppler shift and the target velocity requires knowledge of the angle between the target heading and the radar beam. A new explicit relation is presented which is angle-independent; however, it requires the first and second time derivatives of the Doppler shift. An optimal measuring scheme to obtain those derivatives is suggested, based on phase observations of the received signal and a least squares filter. Error analysis of the angle-independent velocity measurement is provided, and compared with the angle-dependent one.

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WHOI Contribution No. 4935.

TIDAL EFFECTS ON LONG-RANGE SOUND TRANSMISSION

W. Munk, B. Zetler, J. Clark, S. Gill,
D. Porter, J. Spiesberger and R. Spindel

Time series of acoustic travel times over long distances have significant tidal components. We discuss three experiments. First, for a 900 km westward transmission from a moored source southwest of Bermuda, the M_2 constituent (apart from mooring motion) of 8 ms can be accounted for by a variable propagation with and against the 2 cm/s barotropic tidal current. The situation is different for the K_1 and S_2 constituents (which have a significant solar component), particularly for rays with shallow turning points, suggesting an effect from a minute daily variation in the temperature of the upper 100 m. Second, for a 500 km transmission from the Bahamas northward and parallel to the continental margin, the measured M_2 constituent is not in phase with the computed effect of the barotropic tidal current, unlike the westward transmission mentioned above. Here the mode conversion from barotropic to baroclinic tides plays a crucial role: the principal cause of the travel time oscillations in quadrature with the tidal current is a vertical oscillation by several meters (and attendant temperature and sound speed fluctuations) associated with the baroclinic tide just seaward of the continental margin, in the near-zone of mode conversion. Third, for 300 km transmissions from a moored source northwest of Bermuda to both a moored receiver and a land-based receiver, the tidal components in the travel time are dominated by tidally induced mooring motions. The tidal amplitude varies in time as the tidal mooring motion is modulated by the variable current (because of the nonlinear drag), and the current can be so estimated. An important part, possibly a predominant part, of the (nontidal) travel time variation of 0.7 s is evidently associated with the mean mooring motion. The interpretation of the tidal fluctuations in travel time is varied and complex.

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WHOI Contribution No. 4945.

REMOTE ACOUSTIC DETECTION OF ZOOPLANKTON RESPONSE TO FLUID PROCESSES, OCEANOGRAPHIC INSTRUMENTATION AND PREDATORS

Marshall H. Orr

A narrow-beam multifrequency acoustic backscattering system operating at discrete frequencies in the 10-600 kHz band has been used to detect predator-prey interaction, the passive response of zooplankton to fluid processes such as internal waves, lee waves, hydraulic jumps, and the response of organisms to the presence of an oceanographic instrument in the water column. The acoustic flow visualization data illustrate the extent of the vertical and horizontal displacements and mixing of organisms by fluid processes. The data suggest that fluid processes may strongly influence predator-prey distribution in the continental shelf and sound regimes and that the interpretation of biological field data should include the influence of small scale fluid motion on the vertical and horizontal distribution of organisms and nutrients. The predator-prey interaction data indicate that small organisms will move 7-20 m in the vertical to avoid larger organisms. Organisms appear to be able to detect the presence of oceanographic instruments to ranges of ≈ 15 m. At this time it is not known whether the organism detection range is related to the optical properties of the water column or other physical parameters.

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WHOI Contribution No. 4640.

SEASONAL DEPENDENCE OF THE VERTICAL AND HORIZONTAL DISPERSION OF PARTICLES FORMED OR RELEASED DURING THE DISPOSAL OF INDUSTRIAL CHEMICAL WASTES OR SEWAGE SLUDGE

Marshall H. Orr and Lincoln Baxter II

A high-frequency acoustic backscattering system has been used to study the dispersion of particulates released or formed during the disposal of industrial chemical wastes and sewage sludge at the deepwater dumpsite (DWD 106) located 195 km southeast of New York Harbor, New York. Particles associated with waste plumes serve as waterborne tracers which can be acoustically tracked. In addition the data sets can be used to determine the temporal variability of the particle vertical and horizontal

distribution. The acoustic systems provide real-time data to guide chemical and biological sampling of contaminated and uncontaminated sections of the water column.

The acoustic data have shown that the vertical and horizontal distribution of the particulates released at DWD 106 is seasonally dependent, reflecting both the temporal variability of the magnitude of density gradients associated with the seasonal mixed layer and the water mass variability of the area. In a qualitative sense, the acoustic backscattering technique is beneficial to an environmental impact monitoring experiment. However, one of the objectives of developing the technique has been to measure the horizontal and vertical dispersion coefficients of particle plumes. The quantitative analysis of the acoustic data has been limited by navigation inadequacies, the inability to measure vertical shear, the lack of knowledge concerning waste particle size distributions and densities (hence settling rates), and the influence of oceanic turbulence on the particle field.

In press: *Wastes in the Ocean*, I, Ocean Dumping of Industrial Wastes, I.W. Duedall, B.H. Ketchum, D.R. Kester and P.K. Park, eds., John Wiley and Sons, Inc., New York, 1981.

Supported by: NOAA Grants 04-7-158-44054 and NA79AA-D-00030; NOAA Ocean Dumping Grant 04-8-MOI-43; and NORDA Contract N00014-77-C-0196.

WHOI Contribution No. 4620.

ACOUSTIC SENSING OF PARTICLES SUSPENDED BY WAVE-BOTTOM INTERACTIONS

Marshall H. Orr and William D. Grant

The inability to measure the temporal and spatial distributions of particles suspended by the action of combined waves and currents is a limiting factor in obtaining quantitative data to test the various theoretical or empirical models which have been hypothesized to explain the process of particle suspension in a beach, estuary or continental shelf environment. An experiment has been conducted in a wave tank to examine the feasibility of using a 1 MHz acoustic system to study the temporal dependence and spatial distribution of sand grains raised from the tank bottom during the passage of waves of known period and amplitude. Data showing the acoustic detection of fine to medium sized sand grains suspended by surface gravity waves are presented to illustrate the suitability

of using acoustic systems to study the particle-suspension process. Acoustic systems used in conjunction with instruments such as current meters and Reynolds stress measuring devices will allow a more complete understanding of wave/current/bottom interactions and the associated suspension of sediments.

In press: *Marine Geology*, 1981.

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WHOI Contribution No. 4627.

ACOUSTIC IMAGING OF STRUCTURES IN THE UPPER 10 CM OF SEDIMENTS USING A MEGAHERTZ BACKSCATTERING SYSTEM: PRELIMINARY RESULTS

Marshall H. Orr and Donald C. Rhoads

A rapid *in situ* bottom survey technique is needed to provide information about sedimentary structures, boundary roughness and macrofaunal distributions in estuarine, continental shelf and deep sea sediments. We have made preliminary studies using ultrasound imaging as a means of providing this kind of information. Our laboratory studies have shown that a high-frequency acoustic backscattering system operated at 1.6 MHz can accurately image the distribution of laminations and tubes in muddy sediments. We compare the acoustic images with radiographs taken from the same sections of the test sediment to demonstrate the accuracy and resolution of the acoustic record. This acoustic technique could be adapted to a towed sled vehicle to provide *in situ* high-resolution (≥ 1 cm) subbottom (0-10 cm) profiles of sedimentary fabrics and possibly biologic structures.

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WHOI Contribution No. 4867.

OCEAN ACOUSTIC TOMOGRAPHY

Robert C. Spindel

We describe the implementation of an acoustic system employing the principles of time-of-flight acoustic tomography to measure the mesoscale sound speed field of the ocean. We review briefly the fundamental concepts of ocean acoustic tomography and the system performance that must be attained in order to resolve ocean structure such as the mesoscale eddy

field. Special signal processing and instrumentation techniques developed for this application are described. In addition, results of ocean experiments leading to the first (January-September, 1981) demonstration system are presented. We expect to be able to give some measure of the success to this trial deployment.

Published in: Advances in Underwater Acoustics, Proc. Conf. Underwater Acoustics Group, Institute of Acoustics, Edinburgh, England, 1981.

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WHOI Contribution No. 5017.

DECENTRALIZATION OF THE GAUSSIAN MAXIMUM LIKELIHOOD ESTIMATOR AND ITS APPLICATIONS TO PASSIVE ARRAY PROCESSING

Ehud Weinstein

In radar and sonar the trajectory of a radiating source can be estimated by measuring the relative travel time of the signal to several spatially separated receivers. A minimum variance estimate is achieved by simultaneous coherent processing of all receiver outputs. A considerable simplification in estimator structure, and therefore in processor complexity, is obtained by pairwise processing of the receiver outputs. In this paper we determine the performance degradation incurred by decoupling the estimation procedure in such a fashion. We show that if the individual in-band signal-to-noise ratio at each receiver output is much greater than unity, pairwise processing is nearly optimal. If the individual in-band signal-to-noise ratio falls below unity, but the post-beam-forming signal-to-noise ratio (i.e., the product of the individual signal-to-noise ratio and the number of receivers) is large, simultaneous coherent processing yields a level of performance equal to that of pairwise processing with unit signal-to-noise ratio. If the post-beam-forming signal-to-noise ratio does not exceed unity even in the signal frequency band, pairwise processing seriously degrades performance. Finally, we note that decentralizing estimator structure is a powerful technique that may be used to simplify processor complexity whenever large data vectors and/or large parameter sets must be processed.

Published in: IEEE Transactions on Acoustics, Speech, and Signal Processing, ASSP-29, 5, 945-951, 1981.

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WHOI Contribution No. 4418.

OPTIMAL SOURCE LOCALIZATION AND TRACKING FROM PASSIVE ARRAY MEASUREMENTS

Ehud Weinstein

If the signal of a moving source is observed at several spatially separated locations during a common time interval, the received signals exhibit differential delays and Doppler shifts which provide information about source location and velocity. This paper deals with the optimal (in the minimum mean square error sense) source localization and tracking by utilizing differential delay and Doppler observations at a linear array of receivers. We shall be concerned with large source ranges compared with array baseline and with the distance traversed by the source during the observation interval. It is shown that the optimal estimation procedure can be carried out in two sequential steps without any loss in performance. In the first step source location is estimated from the differential delay group of measurements. In the second step source velocity is estimated from the differential Doppler group of measurements and the outcome of the first step. Furthermore, by employing an intermediate track-dependent parameter set, the two-step algorithm yields a closed form solution of the estimation problem.

In press: IEEE Transactions on Acoustics, Speech, and Signal Processing, 1981.

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WHOI Contribution No. 4934.

COASTAL DYNAMICS

THE EFFECTS OF BIOTURBATION ON THE INITIATION OF MOTION OF INTERTIDAL SANDS

W.D. Grant, L.F. Boyer and L.P. Sanford

The results of laboratory flume experiments to study initiation of sediment motion in natural marine sediments (fine to medium sands) are reported. Critical shear stresses were determined for sediment cores from an intertidal region for bed conditions corresponding to: (1) the field state at low tide, and (2) a bioturbated

state. Cores were taken for all seasons of the year over a four-year period. Critical stresses for the natural sediment are compared with stress values for the same sediment in an abiotic (control) state. Critical stresses for the control cores agree well with predictions from Shields curve. In the field state, biological cohesion in the sediment surface increases critical stresses relative to Shields, but never by more than a factor of two. This is well within the normal error bars on Shields curve. Reworking of the sediment surface lowers this value back toward Shields. The magnitude of cohesion and reworking vary seasonally, being highest in the late fall and lowest in the winter. No simple relationship between metabolic activity, temperature and stabilization is supported by the data.

Differences in critical stress values for cores in their initial field state, and in a bioturbated state, indicate that the stability of intertidal sediments may vary over a tidal cycle. The study demonstrates that without controlled experiments, biological processes should not be termed stabilizing or destabilizing because the types of organisms present make relatively different contributions to the sediment stability, and it is the sum total of all effects which is of concern. We suggest that the Shields initiation of motion criterion be used as a standard to define biological stabilization or destabilization.

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WHOI Contribution No. 4960.

MOVEABLE BED ROUGHNESS IN UNSTEADY OSCILLATORY FLOW

William D. Grant and Ole Secher Madsen

A model to predict the roughness in unsteady oscillatory flows over moveable, non-cohesive beds is presented. The roughness over moveable beds is shown to be a function of the boundary shear stress, rather than a fixed geometrical scale as is the case for fully rough turbulent boundary shear flows over immobile beds. The model partitions the roughness into two distinct contributions. These two contributions are due to the form drag around individual bed forms and to the near-bed sediment transport. The form drag over the bed forms is treated explicitly as a function of the boundary geometry and shear stress. The ripples are predicted as a function of the local skin friction and a semi-empirical

expression is derived using standard law-of-the-wall arguments, which gives the ripple or form roughness as a function of the boundary geometry. Favorable comparison of the form drag model with the results of Bagnold's (1946) fixed ripple study is found.

The value of z_0 associated with intense sediment transport in oscillatory flow over a flat bed is determined from Carstens et al.'s (1969) experiments. This value is found to be 7 or 8 grain diameters. It is shown that this value of z_0 is an order of magnitude larger than the thickness of the bed load layer predicted by modifying Smith and McLean's (1977) bed load roughness model to apply in oscillatory flow. An alternative model is suggested for the roughness associated with the maximum thickness of a near-bottom moving sediment layer consistent with Owen's (1964) roughness hypothesis for saltation of uniform grains in air.

The total roughness model is found to compare favorably with Carstens et al.'s (1969) data. In contrast to Smith and McLean's (1977) "steady" flow findings, the results here show that when ripples are present, they account for a significant portion of the boundary roughness.

In press: Journal of Geophysical Research, 1981.

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WHOI Contribution No. 4688.

COMPUTER SCIENCE

A STANDARDIZED SHIPBOARD DATA ACQUISITION SYSTEM

K.R. Peal and E.C. Mellinger

A simple digital data transmission standard is described which is suitable for acquisition and distribution of local sensor data aboard ship. The standard protocol, using bit serial ASCII characters and a polled address control structure, allows a two wire current loop to serve as a multi-access channel for transmission of ship parameter data. Sensors and display devices are located at convenient points throughout the ship and interfaced to the loop with modular low cost microprocessor hardware, using a well defined interface specification. Data are acquired from and distributed to these interface modules by a centrally located controller, which can be

any one of a wide variety of devices. Interface modules, controllers, and other equipment conforming to the standard can be freely interchanged among users, ships, and institutions, allowing a data acquisition system to be easily created by interconnecting functional elements.

A system has been designed using the proposed standard and installed aboard R/V ATLANTIS II. Several months' experience with the system verifies that the basic concepts are valid. Operation is extremely simple and good quality data have been acquired reliably under varying conditions over a period of several months.

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WHOI Contribution No. 4908.

GENERAL ENGINEERING

A FEASIBILITY STUDY FOR A VERSATILE DEEP SEA, MULTILEG, STABLE CABLE ARRAY

Henri O. Berteaux and Robert G. Walden

The purpose of this study is to investigate the feasibility of designing, building, and deploying a large, stable, multileg, deep ocean cable array with a service life of at least five years, and to assess the cost of such an array.

The study first defines the essential desirable features of the array. It then briefly describes a number of candidate configurations which can meet these requirements, point out their advantages and disadvantages.

The study then undertakes an array comparative stability analysis. The Fortran computer program DESADE was used to perform this comprehensive study. Current induced displacements and stress levels of simple and complex arrays were computed using this program. The results thus obtained greatly helped quantify their relative merit.

Based on this analysis and on the array requirements previously defined, a candidate array is selected for preliminary design. This design essentially consists of the rational selection of type, size, and materials for the bouys, cables, and anchors of the prototype array. Safety factors compatible with the five years' life expectancy are confirmed by additional

computer runs, using operational and survival current conditions.

The successful deployment and practical servicing of a deep sea implanted array require careful planning and detailed preparation. The next phase of this study is to outline a deployment scenario, and to indicate the different methods for servicing the array. Power sources and methods of data retrieval are considered. Use of manned and unmanned submersibles is contemplated.

The last phase of the study is an estimate of the cost of the prototype array components.

The report concludes that such an array is feasible, that it can be implanted with a high expectation of reliability and that it can be a safe and stable structure from which to conduct divers novel and useful scientific experiments.

WHOI Technical Report 81-13.

Supported by: ONR Contract N00014-79-C-0894.

HYDRODYNAMICS OF CTD INSTRUMENT PACKAGES

Michael F. Cook

This report is part of a research project conducted at the Woods Hole Oceanographic Institution to improve the flight characteristics of CTD instrument packages. Improvement of these cable lowered instrument packages could allow their use in more severe weather conditions. It could improve the quality of the measurements.

This report presents the development of a simplified mathematical model of the CTD package flight characteristics. This computer model was exercised to perform a sensitivity analysis of different versions of CTD packages.

Part of the research project includes scale model testing. The second part of the report discussed pertinent flow similarity criteria and proposes a scheme for building a CTD half-scale model.

Finally, recommendations to improve the hydrodynamic behavior of the present CTD configuration are summarized at the end of the report.

WHOI Technical Report 81-76.

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G E O L O G Y

EAST PACIFIC RISE AT 21°N: THE
VOLCANIC, TECTONIC, AND HYDROTHERMAL
PROCESSES OF THE CENTRAL AXISRobert D. Ballard, Jean Francheteau,
Tierre Juteau, Claude Rangan and
William Normark

Photographs obtained by the ANGUS survey system at 21°N reveal many similarities to the geological processes delineated at other spreading centers and in particular those observed in the Galapagos Rift at 86°W. The region of recent volcanism is restricted to a narrow zone (Zone 1) approximately 1 km wide. This suggests that the width of the magma chamber feeding these flows is also narrow at the top. Variations in sediment cover are used to subdivide the flows within Zone 1 into three sheet-flow/pillow-flow pairs. The youngest pair appears to have erupted from a linear fissure 8 km long running parallel to the valley axis. This fissure is part of a larger en echelon pattern of eruptive fissures. Active hydrothermal vents associated with the youngest flows are situated directly above the apparent eruptive fissure. The high (350°C) temperature for some of the fluids exiting from the vents suggests a highly restricted circulation system involving, at times, little to no mixing with cold seawater. The lava terrain in the remainder of Zone 1 and bordering regions is characterized by extensive fracturing, further suggesting a narrow upper dimension to the magma chamber and also that subsurface hydrothermal deposition of massive sulfides may lead to a reduction in the mixing processes.

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WHOI Contribution No. 4561.

CRUSTAL PROCESSES OF THE
MID-OCEAN RIDGERobert D. Ballard, Clifford A.
Hopson, Harmon Craig, Bruce P.
Luyendyk, John Edmond, Kenneth
Macdonald, Marco Einaudi, J. Morton,
Robin Holcomb, John Orcutt,
Heinrich D. Holland and Norman Sleep

Independent geological and geophysical investigations of the Mid-Ocean Ridge have begun to focus on the nature of the magma

chamber system underlying its central axis. Thermal models predict, except for extremely slow spreading rates, the existence of a steady-state chamber beneath a thin crustal lid ranging in thickness from 2-13 km. Seismological studies reveal the existence of a low velocity zone beneath segments of the East Pacific Rise which is thought to correspond to a chamber system having a half-width of approximately 10-5 km. These estimates compare favorably to ones derived separately through petrological investigations of deep-sea drilling results, various sampling programs, and field and laboratory studies of ophiolites. The chamber is thought to be wing-shaped and continuously opens; fed from the center, while simultaneously solidifying at the sides as spreading carries the two halves apart. Progressive fractionation occurs by crystal settling coupled with repeated replenishment and magma mixing in an open, steady-state system. Near-bottom studies reveal that the zone of extrusion above the chamber is narrow, but more important, its eruptive history is cyclic in nature in conflict with a steady-state model. On-bottom gravity data at 21°N on the East Pacific Rise reveal a negative gravity anomaly which may be related to the upper-most part of the chamber. The anomaly is only two kilometers wide and one kilometer below the seafloor. This feature may be associated with a short-term upper magma reservoir. The cyclic volcanic activity is directly related to the active phase of hydrothermal circulation responsible for the observed negative thermal anomaly. The volume of water involved in this circulation is equal to the entire ocean passing through the accretion zone approximately every eight million years. This is about half a percent of the world's rivers, but the effective transport rates of elements are comparable to those of rivers in that anomalies for individual elements are frequently between one hundred and one thousand times the average river composition. The degree of subsurface dilution determines the final exit temperature and composition of the hydrothermal fluids, ranging from manganese domination at extreme dilution to iron at intermediate levels to sulphide deposition when low dilution occurs. The discovery of massive sulfide deposits on the East Pacific Rise is destined to have a profound impact on our understanding of ore-forming processes. Whether or not it will have any economical significance remains to be seen.

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1981.Supported by: ONR Contract N00014-
79-C-0071.

WHOI Contribution No. 4787.

THE GALAPAGOS RIFT AT 86°W
 5. VARIATIONS IN VOLCANISM, STRUCTURE,
 AND HYDROTHERMAL ACTIVITY ALONG A
 30-KILOMETER SEGMENT OF THE RIFT VALLEY

Robert D. Ballard, Tjeerd H. van Andel
 and Robin T. Holcomb

A 30-k segment of the Galapagos Rift near 86°W has been mapped in detail using the ANGUS towed camera system, the submersible ALVIN, and multi-narrowbeam sonar data. Recent volcanic activity and active hydrothermal circulation are evident along the entire length of the segment mapped. There are, however, clear along-strike variations in these processes which render previous two-dimensional models obsolete. Although alternate explanations are possible, eruptive sequences appear to begin with the outpouring of surface-fed sheet flows and end with more channelized pillow flows. In the western portion of the rift studied, sheet flows dominate with the entire valley floor covered by recent flows associated with a broad shield volcano. The eastern portion, on the other hand, is narrower; consisting primarily of less voluminous pillow flows of apparently the same youthful age. Three possible models for the volcanic evolution of this rift segment are presented. According to the first model, the extrusive portion of the crust is formed by a distinct volcanic episode, followed by a long period of volcanic quiescence. The volcanic phase begins with voluminous sheet flows emerging from numerous eruptive fissures, which in time evolve into a narrow pillow ridge. Farther along-strike, where the flows are smaller and the extrusive zone narrow, the marginal portions undergo continued fissuring and subsequent uplift to form marginal highs and lows. This deformational activity also affects the extrusive zone once volcanic activity ends, converting the distinctly lobate topography of the active period into highly lineated fault-controlled terrain. According to the second model, extension and volcanism can be viewed as a continuous process without major periods of volcanic quiescence. The initial lava flows of a new eruptive sequence fill low areas, frequently spilling over local sills and flooding much of the rift valley. These sheet flows are then capped by pillow ridges, but from an aerial view sheet flows dominate, since they can flow over much greater distances. In the third model, along-strike differences in flow type arise from ephemeral differences in spreading rate along adjacent segments of the rift separated by transient transform faults or adjacent segments of en echelon spreading segments. In this third model, eruptions dominated by sheet flows are associated with a faster spreading element than

eruptions dominated by pillow flows. Active hydrothermal vent fields were found throughout the study area as well as numerous yellow and other accumulations of what appear to be massive sulfide deposits. These latter deposits are not associated with active venting, apparently reflecting previous active hydrothermal phases when the exiting temperatures were sufficiently high to permit surficial sulfide deposition. The active vent fields exhibit along-strike variations in their exiting temperatures, either due to ephemeral differences in spreading rate or variations in the volcanic flow sequences.

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WHOI Contribution No. 4782.

SUBMERSIBLE STRUCTURAL STUDY OF TAMAYO
 TRANSFORM FAULT: EAST PACIFIC RISE,
 23°N (PROJECT RITA)

P. Choukroune, P.J. Fox, M. Seguret,
 J. Francheteau, H.D. Needham, T. Juteau,
 R.D. Ballard, W. Normark, A. Carranza,
 D. Cordoba, J. Guerrero and C. Rangin

A submersible structural study of Tamayo transform fault, the second field study of an oceanic transform, was conducted with the diving saucer CYANA as part of the international Project RITA. On the basis of the surface ship surveys and deep-tow traverses made prior to the diving program, the four successful dives of CYANA established the geometry of the presently active shear zones and demonstrated that the median ridge of the Tamayo transform is tectonically inactive. The dive results require the presence, in an area marked by diapir-like bodies, of an extensional relay zone linking the two offset shear zones which trend about 110°.

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 the Mexican Government.

VOLCANICS AND STRUCTURE OF THE FAMOUS
 NARROWGATE RIFT: EVIDENCE FOR
 CYCLIC EVOLUTION: AMAR 1

Kathleen Crane and Robert D. Ballard

A near-bottom photographic survey on

the Mid-Atlantic Ridge from the FAMOUS region south to Transform B reveals structural and volcanologic evidence for an alternating widening and narrowing rift valley. Extension wedges appear to be propagating south from Transform A and north from Transform B. These merge at Mt. Mars, where the rift valley is narrowest and shallowest (Narrowgate), giving the valley a symmetrical hourglass shape. Three major volcanic en echelon lineaments trend N10°E, 10° oblique to the strike of the inner walls. Faulting and fissuring are antisymmetrical across the rift valley in contrast to the major extension. This contrasting antisymmetry reflects the surficial distribution of stress across crust of varying strengths, whereas the large-scale wedge phenomenon determines the periodicity of transition from a narrow valley to a wide valley. Using vector analysis, the extension wedges are propagating at about 9 cm/yr toward each other. At this rate a narrow rift valley will be fully transformed into a wide rift in 0.64 m.y.

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WHOI Contribution No. 4562.

FIRST MANNED SUBMERSIBLE DIVES ON THE EAST PACIFIC RISE AT 21°N (PROJECT RITA): GENERAL RESULTS

J. Francheteau, H.D. Needham, P. Choukroune, T. Juteau, M. Seuret, R.D. Ballard, P.J. Fox, W.R. Normark, A. Carranza, D. Cordoba, J. Guerrero and C. Rangin

A submersible study has been conducted in February-March 1978 at the axis of the East Pacific Rise near 21°N. The expedition CYAMEX, the first submersible program to be conducted on the East Pacific Rise, is part of the French-American-Mexican Project RITA (Rivera-Tamayo), a three-year study devoted to detailed geological and geophysical investigation of the East Pacific Rise Crest. On the basis of the 15 dives made by CYANA in the axial area of the Rise, a morphological and tectonic zonation can be established for this moderately fast spreading center. A narrow, 0.6 to 1.2 km wide zone of extrusion (zone 1), dominated by young lava flows, is flanked by a highly fissured and faulted zone of extension (zone 2) with a width of 1 to 2 km. Further out, zone 3 is dominated by outward tilted blocks bounded by inward-facing fault scarps. Active or recent faults extend up to 12 km from the axis of extrusion of the East Pacific

Rise. This represents the first determination from direct field evidence of the width of active tectonism associated with an accreting plate boundary. Massive sulfide deposits, made principally of zinc, copper and iron, were found close to the axis of the Rise. Other signs of the intense hydrothermal activity included the discovery of benthic fauna of giant size similar to that found at the axis of the Galapagos Rift. We emphasize the cyclic character of the volcanicity. The main characteristics of the geology of this segment of the East Pacific Rise can be explained by the thermal structure at depth below this moderately fast spreading center. The geological observations are compatible with the existence of a shallow magma reservoir centered at the axis of the Rise with a half-width of the order of 10 km.

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WHOI Contribution No. 4228.

INSTRUMENTATION

DIRECTIONAL PEDESTAL-FREE LASER DOPPLER VELOCIMETRY WITHOUT BIASING: PART 1.

Y.C. AGRAWAL AND J.R. MCCULLOUGH

The spatial structure of the optical field on the detector of a laser Doppler velocimeter is examined. It is shown that for sufficiently small scatterers, the optical field is a traveling wave of shape determined by the detector optics alone. The direction of travel of the optical field reflects that of the scattering particle. Thus, the direction of motion of the particle is determined by temporal correlation of photocurrents from two spatially offset detector arrays. The arrays also eliminate the Doppler pedestal as shown by Ogiwara (1979). In this paper, the theory of the new method is described; experimental implementation will be described in a complementary paper.

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WHOI Contribution No. 4791.

BACKSCATTER LASER VELOCIMETER FOR ENERGETIC BOTTOM BOUNDARY LAYERS: THE OPTICAL SIGNAL

Y.C. Agrawal, W.E. Terry, Jr.
and A.J. Williams 3rd

The optical signal from a dual-beam backscatter laser Doppler velocimeter designed for oceanographic usage will be described both theoretically and experimentally. The instrument was constructed to simulate, in the laboratory, the strength and behavior of the optical signal as a function of mass concentration of natural particles in water - a subject of concern in the study of high energy benthic boundary layers. It has been found that with proper design, the predominant mode of signal degradation with increasing particle loading is caused primarily by increased shot noise due to signal attenuation alone. Secondly, the signal is observed to be in the single-scatterer mode at particle concentrations of up to 5 mg/. Variations in observed signal-to-noise ratio will be described and compared with theoretical calculations.

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WHOI Contribution No. 4629.

INTERPRETATION OF VELOCITY PROFILES MEASURED BY FREELY SINKING PROBES

Peter J. Hendricks and George Rosenbusch

For most freely sinking instruments that measure horizontal velocity, it is necessary to understand the response of the vehicle to the flow properly to interpret the measurements. Three physical effects that influence the measurements are identified and modeled. First, the vehicle tends to follow the low vertical wave number variability in the velocity profile. A linearized model of the vehicle motion shows that the horizontal velocity of the vehicle is the low pass of the true current profile, while relative velocity measured by a velocity sensor on the vehicle is the high pass. The filter has a single pole at a wave number that does not depend on the sinking rate. Second, when there is a horizontal velocity sensor on the vehicle and the sensor is displaced from the vehicle's center of mass, there is a phase difference between the measured profile and the vehicle motion that is accounted for. This phase difference significantly increases the apparent energy in low vertical wave number velocity fluctuations. The third effect arises when the drag on the vehicle is distributed along the length of the vehicle and cannot

be modeled adequately as a point force. The effect of the distributed drag force is only significant for high vertical wave number variations.

The above results are applied in correcting measurements from a freely sinking velocity profiler. The corrected measurements are in good agreement with simultaneous velocity measurements from an instrument whose performance in the band of comparison does not depend on the vehicle motion.

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WHOI Contribution No. 4006.

SURVEY OF AND PROBLEMS WITH ACOUSTICALLY PULSED TRANSPONDER NAVIGATION SYSTEMS AT THE WOODS HOLE OCEANOGRAPHIC INSTITUTION

John F. Loud

This paper presents a brief survey of ideas about acoustic transponder navigation which has been taken from working systems used in oceanographic research at the Woods Hole Oceanographic Institution (WHOI). These systems have been designed to work effectively because of the presence of an operator. The vehicular navigation has its base of operations aboard a surface ship which sets a network of transponders, surveys the net, and where the survey data is reduced to produce the relational positions for navigating an underwater vehicle. In most cases, the underwater vehicle is actually navigated from aboard the ship. If it can be assumed that the setting and surveying of the transponder net is independent of navigating an underwater vehicle, a logical extension to these techniques can be utilized to navigate a remote, independent submersible by acoustically pulsed transponders. Problems of acoustic pulse transmission and reception, environmental noise, and signal to noise ratio and considerations of effective range must be overcome to navigate effectively. Once these are overcome for a remote underwater vehicle, the problem is reduced to one of guidance.

In order to navigate an underwater vehicle within a transponder net, the net must be installed and surveyed. Several techniques in surveying and calibrating a transponder net are included. In many respects, this is a more complex task than navigation within the net. Planning the

layout and setting the transponders, then collecting the proper set of survey points is a time consuming task, but if accomplished properly, the data may be used to calibrate the relational parameters of the net accurately (within 12-20 cm).

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A SIX-PORT UNDERWAY WATER SAMPLING SYSTEM

Marshall H. Orr and Clifford L. Winget

A six-port water sampling system has been constructed to obtain underway (0 to 2 m/s) variable depth (0-100 m) uncontaminated sea water samples. The water handling components of the system consist of six 150 m lengths of TFE teflon hose and six water pumps which are constructed with polypropylene housings. Each of the six water sampling ports are separated by 1 m in the vertical and delivered $\approx 5.7 \text{ L/min}$ of sea water to deck level. The water sampling system's configuration, operating characteristics and present limitations will be discussed.

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WHOI Contribution No. 4610.

P H Y S I C A L

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

REVERSIBLE AND IRREVERSIBLE FINE STRUCTURE

Y.J.F. Desaubies and M.C. Gregg

Various statistics of temperature profiles are examined in an attempt to distinguish irreversible structures due to mixing from reversible distortions induced by internal wave straining. Even if all the low gradient regions were the result of mixing events, an analysis of the profiles shows that such events are rare and most often incomplete. An upper bound on the mixing effectiveness is obtained; it increases as the vertical scale decreases. Taking next the opposite view that internal wave straining is the sole process, an

analytic model is developed to calculate the probability density function of temperature gradients. The model considers the straining by a weakly nonlinear Gaussian internal wave field of a linear temperature profile. The nonlinearity of the field is essential to account for the skewness of the probability distributions. Comparisons with data are quite satisfactory at scales larger than about 2m, less so at smaller scales. We conclude that nonlinear effects are important; at scales larger than approximately 2m straining is dominant with very little mixing, while at smaller scales irreversible structures are more prevalent.

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WHOI Contribution No. 4805.

A COMPOSITE SPECTRUM OF VERTICAL SHEAR IN THE UPPER OCEAN

A.E. Gargett, P.J. Hendricks, T.B. Sanford, T.R. Osborn and A.J. Williams 3rd

Results from three separate velocity profilers, operated nearly simultaneously in the northwest Atlantic in 1975, are used to form a composite shear spectrum over vertical wavelengths from 100 m down to a few centimeters. This exercise constitutes an intercomparison of the three different measurement techniques and reveals a shear spectrum which is approximately flat at a WKB-scaled level from $k = 0.01 \text{ cpm}$ through $k_0 \approx 0.1 \text{ cpm}$, then falls as k^{-1} to a buoyancy wave number $k_b = (N^3/\epsilon)^{1/2}$ determined by the local average Vaisala frequency N and the volume-averaged dissipation rate ϵ . Various consequences of the observed shear spectral shape are explored.

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WHOI Contribution No. 4943.

THE ROLE OF DOUBLE DIFFUSION IN A GULF STREAM FRONTAL INTRUSION

Albert J. Williams 3rd

Double diffusive convection is possible where large vertical gradients in temperature and salinity tend to compensate in density. Frontal intrusions have these

large gradients and can provide the possibility for a salt finger interface at one boundary and a diffusive interface at the other. But large vertical gradients of velocity are present at the boundaries of intrusions, which cause mechanical stirring and turbulent mixing as well. In the exceptionally active intrusions at the Gulf Stream Front near 38°N 69°W, a convective process resulting from incomplete mechanical mixing was observed photographically on both intrusive boundaries.

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WHOI Contribution No. 4243.

S T A T I S T I C S

REPLICATION IN CONTROLLED MARINE SYSTEMS: PRESENTING THE EVIDENCE

Woollcott Smith, Victoria R. Gibson and J. Frederick Grassle

The statistical design and analysis of large enclosed marine experiments differs from small well-controlled laboratory experiments. Although there are usually only a few large enclosures in an experiment, information on the replicability of an experiment is contained in the time series response in each enclosure. This is particularly true when the experimental unit is subject to a control period, followed by an experimental period and then a return to control conditions.

Zooplankton response to mercury in the CEPEX experiment and the benthic community's response to No. 2 fuel oil in the MERL experiment were analyzed. Community dissimilarity was used as the measure of difference between the experimental and control systems. In both experiments the time series response, i.e., the dissimilarity between control and experimental communities, followed a pattern similar to the concentration of pollutant in the experimental systems.

In press: Marine Mesocosms, 1981.

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WHOI Contribution No. 4789.

S U B M E R S I B L E S

WEIGHT AND STABILITY OF DSRV ALVIN, 1980

Arnold G. Sharp

ALVIN returned to Woods Hole in mid-February 1981 for a maintenance period that extended through June of that year. Mechanical and electrical systems were serviced and repairs were made to the structural frame and the forebody syntactic foam package. Since no major modifications were made to the vehicle the inclining experiments were omitted after reassembly. The usual weight and stability computations as programmed for the W.H.O.I. Sigma-7 computer were performed and are presented. Results of the tethered trim dive are tabulated, and miscellaneous related hand calculations are included.

WHOI Technical Memorandum.

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DEPARTMENT OF PHYSICAL OCEANOGRAPHY

Valentine Worthington, Department Chairman

COASTAL DYNAMICS

Supported by: NSF Grant OCE78-03380 and
the WHOI Coastal Research Center.

A COMPARISON OF LONG COASTAL TRAPPED WAVE
THEORY WITH OBSERVATIONS OFF PERU

Kenneth H. Brink

The agreement between coastal trapped wave theory and observation is studied for the case of observations made off Peru during the 1977 CUEA JOINT-II experiment (Coastal Upwelling Ecosystems Analysis Program). Wave properties are calculated using a numerical model with realistic, horizontally uniform stratification and realistic bottom topography. These properties are then explored as a function of the ratio of the first internal Rossby radius of deformation to the shelf-slope width. The agreement of observed and calculated free wave phase speeds is excellent, while modal structures agree tolerably. A forced wave calculation, using observed winds and currents as input, is used to hindcast alongshore currents and sea level in the frequency band where Smith observed free coastal trapped waves during 1977. The model suggests that most of the observed sea level and alongshore velocity fluctuations in the five to ten-day period band are due to free waves originating equatorward of 5°S , while winds between 5°S and 15°S contribute little to the observed variance. Finally, free coastal trapped wave calculations are briefly compared with CUEA observations from off Northwest Africa and Oregon. Generally, the wave calculations appear to be a useful tool in interpretation of the field observations.

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THE EFFECT OF BOTTOM FRICTION ON
LOW FREQUENCY COASTAL TRAPPED WAVES

Kenneth H. Brink

An approximate technique is presented for including the effect of turbulent bottom friction in the forced first order wave equation governing long generalized coastal trapped waves. The resulting governing equations include both damping and a cross shelf and vertical phase shift. A set of examples shows that damping of free waves decreases as the static stability increases, consistent with the inhibition of vertical motions by stratification.

In press: Journal of Physical
Oceanography.

ON THE STRUCTURE OF
TRANSIENT UPWELLING EVENTS

Gabriel T. Csanady

Nearshore transects, following the development of transient coastal upwelling, characteristically show "intermediate" density fluid occupying the immediate nearshore band. Large cross-shore particle excursions during the development of upwelling may be inferred from before and after transects, surface layers moving seaward, intermediate density fluid shoreward through a distance of the order of kilometers, the bottom layers also shoreward by a lesser amount. Some inevitable vertical mixing together with the large cross-shore displacements results in efficient cross-shore mass exchange.

The main dynamical features of similar events may be investigated by means of three-layer models. Linear theory is conveniently discussed first, the conclusions of which are easily generalized to multilayer models. Finite amplitude (i.e., "full") upwelling is then considered using a potential vorticity conserving impulsive model. The results show that the wind "peels" off the surface layer over which the wind stress is effectively distributed. Thus, the next lightest layer becomes exposed to the atmosphere. The lower layers generally respond in the barotropic mode, becoming "equally stretched" on the removal of the surface layer, except within a distance of the order of the baroclinic radius of deformation from the pycnocline outcropping. The maximum velocity of the jet associated with the pycnocline outcropping is limited to an effective densimetric velocity. Cross-shore displacements behave in the model pretty much as in the observed cases.

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Oceanography.

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SHELF CIRCULATION CELLS

Gabriel T. Csanady

Considerable insight has recently been gained into the dynamics of continental shelf circulation through a simplification of the governing equations, resulting in a parabolic equation for the pressure field.

Solutions of this equation appear to model realistically various important flow phenomena, notably the effects of winds and coastal geography in setting up half-open coastal circulation cells, and an associated trapped pressure field. Circulation cells should be established mainly on the inner shelf, according to theory, i.e. within about 30 km of the coast, and should be important agents of mass exchange. In the present article the theory of shelf circulation is reviewed with an emphasis on its most general predictions. Then the question is examined of how a considerable body of evidence on coastal sea-level variations in response to wind, longshore sea level gradients, longshore and cross-shore currents can be interpreted in the theoretical framework.

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THE K₁ TIDE ON THE CONTINENTAL SHELF FROM NOVA SCOTIA TO CAPE HATTERAS

Peter R. Daifuku and Robert C. Beardsley

A description is given of the K₁ tide over the northeast continental shelf off North America from Nova Scotia to Cape Hatteras. Analyzed pressure data obtained from W. Brown (University of New Hampshire) have been used to draw up the K₁ cotidal map and existing current data have been analysed to give the associated velocity map. Offshore, there is a sweep of the tide from north to south, in general agreement with what is known of the oceanic K₁ tide in the North Atlantic. On the shelf, there is a trapping of phase lines to the coast, creating, in particular, a virtual amphidrome south of Cape Cod. Maximum amplitudes of around 15 cm are found in the Gulf of Maine, lowest around 7 cm south of Cape Cod. The K₁ currents are generally barotropic and current ellipses are aligned with the local topography. Maximum currents of about 10 cm/sec are found south of Cape Cod.

A simple model for the K₁ pressure field is developed using the free and forced inviscid barotropic waves on a two-dimensional shelf. The theoretical solutions are fitted to the K₁ pressure data using a least squares method. The model results confirm that the K₁ tide is composed of both a Kelvin wave and a shelf wave, with the Kelvin wave dominating the pressure field, and the shelf wave dominating the current field. The two free waves account for 99 percent of the

variance of the difference of the observed pressures and the calculated forced wave, but unfortunately, some of the observed features are not accurately reproduced. Possible model improvements should include the addition of bottom friction and longshore topographic variations (especially the changes in shelf geometry associated with the Gulf of Maine).

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THE SEASONAL HYDROGRAPHY AND CIRCULATION OVER NANTUCKET SHOALS

Richard Limeburner and Robert C. Beardsley

Bimonthly hydrographic surveys were begun in May 1978 to measure the spatial structure and temporal variability of the temperature and salinity fields about Nantucket Shoals over one annual cycle. Moored current meters were also deployed in January 1979 and in July 1979 to directly measure the current field and examine low-frequency current variability over the shoals. Surface temperature maps obtained during the spring and summer show cores of relatively cold, nutrient-rich water along the northeastern edge of the shoals which result from the advection of stratified Gulf of Maine water into the tidally well-mixed region over the shoals. The regional T/S (temperature/salinity) distribution during the spring and summer shows a bimodal distribution: a Gulf of Maine mode and a shelf mode. The Gulf of Maine mode dominates the local water structure over the northern part of Nantucket Shoals, and a mixture of the two modes dominates the southern shoals. The presence of the shelf mode in the Great South Channel region implies inflow here through the Channel. Advection and tidal mixing, and to a lesser extent, local air/sea heat exchange and wind forcing, directly influence water properties over the shoals. Direct current measurements over the eastern shoals near 41°30'N suggest a southward flow of order 10 cm/sec, indicating a minimum transit time of order 10 days through this eastern region. While local wind forcing can influence the low frequency current variability over the shoals (and indeed reduce the minimum transit time to a few days during periods of strong northeast winds), the mean south and southwestward flow over the shoals appears to be driven on monthly and longer time scales by the larger scale regional circulation regime in the western Gulf of Maine, Georges Bank, and New England shelf region.

In press: Journal of Marine Research.

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THE ESTUARINE CHARACTER OF THE GULF OF NICOYA, AN EMBAYMENT ON THE PACIFIC COAST OF CENTRAL AMERICA

Arthur D. Voorhis, Charles E. Epifanio,
Don Maurer, Ana I. Dittel and
Jose A. Vargas

Hydrography and exchange processes in a tropical estuary, the Gulf of Nicoya, Costa Rica, are described from data collected in 1979 and 1980. The measurements and analyses were made in both the dry season and wet season and include temperature, salinity, and density at twenty locations in the Gulf and currents (over a semi-diurnal tidal cycle) at five locations. These new results enlarge on the early study by Peterson. Circulation in the lower Gulf shows a marked east-west asymmetry due to the predominant runoff along its eastern shore from Rio Barranca and Tarcoles. The freshened surface water from the upper Gulf combines with the runoff from these rivers and flows southward along the eastern side of the lower Gulf. This flow is compensated by a northward flow of more saline water on the western side at all depths and on the eastern side along the bottom. The boundary between the southward and northward surface flow is marked by a strong salinity front in the rainy season. There is a rapid increase in tidal energy density toward the shoaling northern reaches of the lower Gulf, between Negritos and Puntarenas. Enhanced mixing must accompany this increase, and direct measurements in the constriction between San Lucas and Puntarenas shows that tidal mixing is dominant in transporting salt into the upper Gulf against the freshwater runoff.

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FINE SCALE PROCESSES

OBSERVATIONS OF SALT FINGERS IN THE CENTRAL WATERS OF THE EASTERN NORTH PACIFIC

Ann E. Gargett and Raymond W. Schmitt

This paper presents direct measurements of the temperature signature of salt

fingers, observed by a horizontally towed temperature sensor at a station in the middle of the subtropical gyre in the eastern North Pacific. The observed spectral shape compares favorably with predictions from the spectral model of Schmitt, in which a wide range of finger wavenumbers grow. The buoyancy flux due to temperature across the fingering interface is estimated by three methods: a "direct" determination from the observed temperature gradient variance, and predictions from two laboratory flux laws. The order-of-magnitude agreement among these estimates is an encouraging start to the problem of parameterizing the heat, salt and buoyancy fluxes associated with salt fingering in the Central Waters of the subtropical gyres, a very real problem in view of the widespread occurrence of salt-fingering signatures in the towed temperature records.

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SALT FINGERS: LIMITS TO GROWTH

Terrence M. Joyce

The theory of long, thin salt fingers is extended to allow for a finite length. The temporal evolution of a marginally unstable disturbance is then examined as it interacts with and modifies the basic state, which is constrained to be at rest in hydrostatic equilibrium. After a few e-folding periods of initial exponential growth, salt fingers will have modified the horizontally-averaged salinity field to the extent that it is no longer unstable. For the cases considered, a stable steady-state is achieved between heat and salt transport by salt fingers and diffusive adjustment of the horizontally-averaged field. The nature of the approach to the steady state is studied numerically and is oscillatory for long fingers with large initial growth and monotonic for short fingers with small initial growth rates. It is suggested that long fingers will be unstable leading to small, local instabilities and a resulting layered structure. Further, salt fingers with large growth rates are more likely to be transient in nature rather than dynamically steady.

In press: Journal of Marine Research.

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FINESTRUCTURE AND MICROSTRUCTURE IN THE NORTH ATLANTIC CURRENT

Raymond W. Schmitt and Daniel T. Georgi

The relationship between intrusive finestructure and optical microstructure was studied by simultaneous CTD (conductivity-temperature-depth sensor) tow-yos and deployments of the shadowgraph profiler SCIMP (self-contained imaging microprofiler). Strong thermohaline intrusions, 5 to 50 m thick, were tracked laterally for 5 to 10 km in the front associated with the North Atlantic current. Some of the intrusions showed significant cross-isopycnal slopes, consistent with the hypothesis that double-diffusion is causing the intrusions to cross density surfaces. The SCIMP shadowgraphs displayed clear images of salt fingers at the lower boundaries of warm salty intrusions, confirming that double-diffusion is an active mixing process in frontal interleaving zones. In addition, significant correlations of the SCIMP optical microstructure with temperature, salinity and velocity finestructure were found. Mixing activity was more likely to occur when the density ratio ($R_\rho = \alpha T_z / \beta S_z$) was near one or when the Richardson number was low. These correlations show that double-diffusion was more common than shear instability in the frontal interleaving zone. In contrast, a SCIMP dive in mid-gyre showed much less activity, no interleaving, and few sites with R_ρ near one. Thus shear instability may account for most of the weak mixing in mid-gyre regimes. The scales of the intrusions are found to be consistent with the double-diffusive generation model of Toole and Georgi. Application of the Joyce lateral mixing model suggests that intrusions are a significant cross-frontal mixing mechanism.

In press: Journal of Marine Research.

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

A ROTATING FLUME WITH UNIFORMLY FLOWING, LINEARLY STRATIFIED WATER

Neil Gershenfeld, Robert E. Frazel and
John A. Whitehead, Jr.

A new flume is described which contains a rotating laminar flow with a linearly varying temperature distribution from top to bottom, making it useful for a number of

model experiments in geophysics. Some experimental results in selective withdrawal from this apparatus are presented as examples of the types of problems that can be addressed.

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SHIPBOARD ACOUSTIC PROFILING OF UPPER OCEAN CURRENTS

Terrence M. Joyce, David S. Bitterman, Jr.
and Kenneth E. Prada

The ability to map the oceanic velocity field from ships would greatly enhance our ability to describe the energetics of the oceanic eddy field, structure of narrow and intense currents, and provide some reference field for dynamic calculations of geostrophic currents. One technique which contributes toward this goal is presented. The shipboard system consists of a micro-processor-controlled data logger which collects and formats data from a four-beam Ametek-Straza 300 kHz doppler current profiler, heading from the ship's gyro, and navigation information from a LORAN-C receiver and a satellite navigation unit. Data are recorded on magnetic tape and some real-time calculations are made. The system has been used in a May 1981 cruise on R/V OCEANUS in the northwest Atlantic and some ten-minute, vector-averaged current profiles have been presented on a section across the Gulf Stream. Horizontal currents have been profiled to 100 meters depth. Time averaging is required to remove effects of ship motion. Errors in our ability to profile ocean currents while underway are estimated to be 5-10 cm s⁻¹ for absolute currents, and 1-2 cm s⁻¹ for relative changes in a ten-minute vector average.

In press: Deep-Sea Research.

Supported by: NASA Grant NAG 1-91.

ON THE LOSS OF DISSOLVED OXYGEN IN NANSEN BOTTLE SAMPLES FROM THE DEEP ATLANTIC OCEAN

L. Valentine Worthington

In the tropical and subtropical Atlantic Ocean loss of dissolved oxygen nearly always takes place within Nansen bottles between the time that they close, in deep water, and the time that the samples are drawn for analysis. The

principal cause of this oxygen loss, in routine stations, is shown to be degassing; deep samples, rich in oxygen, are heated to above their saturation point as they are brought up through the thermocline and surface layers. Niskin bottles, which are far better insulated, are immune from this fault. An example of oxygen loss due to chemical reaction within the Nansen bottle, and an example of oxygen loss due, possibly, to bacterial respiration, are also described.

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INTERNAL WAVES

ABSORPTION OF INTERNAL WAVES BY THE BENTHIC BOUNDARY LAYER

Eric D'Asaro

The interaction of near-inertial velocities with the benthic boundary layer above a flat bottom is investigated using a diagnostic model and a three-month time series of velocity from a fixed array of current meters. The observed near-inertial motions are assumed to be due to internal waves and diurnal tides. If the vertical wavelength of the internal waves is much larger than the boundary-layer thickness, the turbulent stresses acting on the near-inertial motions and the work done by the stresses on these motions can be computed. The boundary layer is estimated to absorb $\sim .003$ to $.024$ ergs $\text{cm}^{-2} \text{s}^{-1}$ from the near-inertial motions, with one-third coming from the K_1 diurnal tide and the rest from the internal-wave field. This is far less than estimated by Leaman and suggests that the benthic boundary layer on a flat bottom plays a minor role in dissipating internal-wave energy. This is also much less than the total energy dissipation in the boundary layer, suggesting that the boundary layer is primarily driven by low-frequency motions, not internal waves. A simple slab model with a linearized quadratic drag law qualitatively explains the near-inertial velocity structure and energy flux observed in the boundary layer.

In press: Journal of Physical Oceanography.

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THE DYNAMIC BALANCE OF INTERNAL WAVES

C. Henry McComas and Peter Müller

For oceanic internal waves with vertical scales larger than 1 m the evolution of the spectrum is adequately described by weak-interaction theory. Based on simple physical arguments, a model for internal-wave energy dissipation predicts dissipation as weak over the same scales, for reasonable values of the total dissipation. Assuming dissipation at small scales, such as in our proposed model, and generation at large scales, a consistent dynamic balance with a constant downscale energy flux under nonlocal nonlinear interactions reproduces the observed spectral dependencies. A small-scale break point at which the total shear reaches a given value, and beyond which dissipation is important, is determined by the level and bandwidth of the energy-containing waves.

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LABORATORY MODELS

THE INTRUSION OF A DENSITY CURRENT ALONG THE COAST OF A ROTATING FLUID

Melvin E. Stern, John A. Whitehead, Jr. and Bach Lien Hua

When light rotating fluid spreads over heavier fluid in the vicinity of a vertical wall (coast) a boundary jet of width L forms, the leading edge or nose of which propagates with speed c along the coast. A certain fraction δ of the boundary transport is not carried by the nose but is deflected backwards (detained) and left behind the propagating nose. Theoretical and experimental results for L , c , and δ are given for a quasi-equilibrium (constant c) regime. Over longer time intervals the laboratory observations suggest that the nose slows down and stagnates, whereupon the trailing flow separates from the coast and an intermittent boundary current forms. These processes may be relevant to the mixing of oceanic coastal currents and the maintenance of the mean current.

In press: Journal of Fluid Mechanics.

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INSTABILITIES OF FLUID CONDUITS IN A FLOWING EARTH - ARE PLATES LUBRICATED BY THE ASTHENOSPHERE ?

John A. Whitehead, Jr.

A laboratory and theoretical study of the stability of conduits of buoyant fluid in a viscous shear flow has been conducted. The object of the study is to explain the formation of discrete islands in island chains such as the Hawaiian Emperor seamount chain, and to investigate a new method by which the variation of shear with depth in the mantle may be determined. The conduits were made by injecting oil into a more viscous oil of greater density. Initially a growing chamber of lower viscosity oil formed near the injector, but when the chamber got sufficiently large it rose as a buoyant spheroid. Behind this trailed a vertical cylindrical conduit through which fluid could continue to rise to the surface as long as the source continued. If the more viscous fluid was sheared laterally, the conduit was gradually rotated to a more horizontal position. The diameter of the conduit increased with time due to a decreasing component of gravitational force along the axis of the conduit. When the conduit was tilted to more than 60° with the vertical, it began to go unstable by developing bumps which ultimately initiated a new chamber which rose to a new spot. In addition, if the Reynolds number of the conduit was greater than approximately ten, an axisymmetric wavy instability appeared in the walls of the conduit and the conduit had to be tilted less before a new chamber was initiated. If shear under the Pacific plate has to tilt buoyant mantle plumes to as much as 60° to form the relatively regular island chains associated with hot spots, most of the shear would be found in a zone with a vertical extent of less than 200 km.

In press: Geophysical Journal of the Royal Astronomical Society.

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LABORATORY MODELS OF CIRCULATION IN SHALLOW SEAS

John A. Whitehead, Jr.

Three laboratory experiments are described. The first was made for the purpose of observing the flow field of circulation in a model by Stommel and Leetmaa. The experiment consisted of a very shallow (one or two centimeters deep) annulus with an inner heated wall of radius 25 cm and a cooled outer wall of radius 57 cm, all mounted on a turntable. When Ekman

number was large the flow was steady and resembled the solutions for a nonrotating estuary by Hansen and Rattray, but when Ekman number was small the flow became time dependent. Values of shear and stratification obtained from theory indicate that the flowing water probably underwent baroclinic instability. It appears that such instability may develop on real shelves.

The second experiment consisted of a shallow sea of constant depth bounded by a deep ocean through a uniformly sloping continental rise. The experiment is cooled from above and there is a region which exhibits sinking convection cells, which form the coldest water. This water then spills off the right hand side of the shallow sea (looking downstream for counterclockwise rotation) and forms bottom water in the deep experimental ocean.

The third experiment is a rotating version of the dam-break problem in which a density current is generated after a barrier has been removed. The rotation causes the current to lean against the right hand wall (looking downstream for counterclockwise rotation) and turbulent eddies are detrained to the side rather than vertically.

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LARGE SCALE OCEANIC HEAT AND WATER PROPERTIES

SEASONAL VARIABILITY IN THE INTERMEDIATE WATERS OF THE EASTERN NORTH ATLANTIC

Nancy A. Bray

Observational evidence of seasonal variability below the main thermocline in the eastern North Atlantic is described, and a theoretical model of oceanic response to seasonally varying windstress forcing is constructed to assist in the interpretation of the observations. The observations are historical conductivity-temperature-depth data from the Bay of Biscay region (2° to 20° W, 42° to 52° N), a series of eleven cruises over the three years 1972 through 1974, spaced approximately three months apart. The analysis of the observations utilizes a new technique for identifying the adiabatically-leveled density field corresponding to the observed density

field. The distribution of salinity anomaly along the leveled surfaces is examined, as are the vertical displacements of observed density surfaces from the leveled reference surfaces. Seasonal variations in salinity anomaly and vertical displacement occur as westward propagating disturbances with zonal wavelength 390 (± 50) km, phase at the eastern boundary of 71 (± 30) days from 1 January, and maximum amplitudes of ± 30 ppm and ± 20 db respectively. The observations are consistent with the predictions of a model in which an ocean of variable stratification with a surface mixed layer and an eastern boundary is forced by seasonal changes in a sinusoidal windstress pattern, when windstress parameters calculated from the observations of Bunker and Worthington are applied.

Supported by: ONR Contract N00014-76-C-0197, NR 083-400.

SOURCES OF EDDY ENERGY IN THE GULF STREAM RECIRCULATION REGION

Harry L. Bryden

Array measurements of current and temperature made for 15 months in the main thermocline of the Gulf Stream recirculation region near 31°N, 69°30'W are analyzed to determine the energy sources for low-frequency fluctuations or eddies and the effect of these eddies on the mean circulation in the region. Eddies are found to gain energy by converting available potential energy contained in the mean circulation at a rate of 3.3×10^{-5} erg cm⁻³ s⁻¹. The signature of this energy gain is an eddy heat flux directed down the mean horizontal temperature gradient. The eddies lose energy in their interaction with the mean currents at a rate of 1.5×10^{-5} erg cm⁻³ s⁻¹. The signature of this energy loss is an up-gradient eddy momentum flux. While the eddies lose energy in interacting with the mean currents, there is no local conversion of eddy energy into mean kinetic energy, hence the eddies do not locally drive the mean flow. Indirect estimates of the divergence of eddy energy flux across the open boundaries of the array suggest that the net import or export of energy from this region is less important than the local energy conversions in the energetics of the eddies. While comparisons with numerical model results are difficult, these observed energy conversions tend to be in agreement with those in Holland and Lin's model and in disagreement with those in Robinson, Harrison, Mintz and Semtner's model.

In press: Journal of Marine Research.

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THE ANTARCTIC CIRCUMPOLAR CURRENT AND THE OCEANIC HEAT AND FRESHWATER BUDGETS

Daniel T. Georgi and John M. Toole

Hydrographic sections that span the Antarctic Circumpolar Current are used to estimate the zonal heat and freshwater transports south of Africa, New Zealand and America. These in turn are used to calculate the exchanges of heat and freshwater between the three major oceans. It is found that both the Atlantic and Pacific lose heat and gain freshwater and that these differences are supplied by a corresponding gain of heat and loss of freshwater in the Indian Ocean. Our results also indicate that the three oceans exchange less heat and freshwater with one another than is suggested by studies based on large-scale integration of air-sea exchanges. As the absolute velocity field is not uniquely known, the magnitude of the calculated losses and gains is sensitive to the choice of a reference level and the horizontal structure of the barotropic transport. In addition, the presence of baroclinic eddies introduces uncertainties into the calculated heat and salt transports. Because of the large relative errors associated with the salt transport calculations, no definitive conclusion is reached for the interoceanic freshwater exchanges. However, the signs of the gains and losses appear to be well determined. Finally, estimates of air-sea exchanges in the Southern Ocean are combined with the heat and freshwater divergences to calculate the meridional fluxes across 40°S. These meridional transports are in general much smaller than those obtained by other investigators employing different methods.

In press: Journal of Marine Research.

Supported by: NSF Grant OCE78-22223.

ON THE TRANSPORT AND MODIFICATION OF ANTARCTIC BOTTOM WATER IN THE VEMA CHANNEL

Nelson G. Hogg, Pierre E. Biscaye,
Wilford D. Gardner
and William J. Schmitz, Jr.

The Vema Channel is a deep passage through the Rio Grande Rise in the South Atlantic through which Antarctic Bottom Water (AABW) must flow on its way northward from the Argentine Basin to the Brazil Basin and eventually into the North

Atlantic. Both dynamic computation and direct current measurement based on recently acquired data indicate that the volume transport of AABW is about $4 \times 10^6 \text{ m}^3/\text{sec}$ northward with a standard deviation of about $1.2 \times 10^6 \text{ m}^3/\text{sec}$. There are no known deep exits for this water out of the Brazil Basin and it is estimated by heat flux balance that if AABW leaves this basin across isopycnals a diffusion rate of $3\text{--}4 \text{ cm}^2/\text{sec}$ so directed is required.

There is a sharp water mass transition between the two basins across the Rio Grande Rise, with AABW in the Argentine Basin being distinctively fresher and colder in the potential temperature range from 0.2°C to 2.0°C at the same density. Cold tongues of fresh water advected into Vema Channel may be thoroughly mixed by lateral eddy diffusion at a rate estimated to be $4 \times 10^6 \text{ m}^2/\text{sec}$. This process demands a supply of Brazil Basin AABW from the north consistent with an observed weak southward flow to the east of the much more intense northward jet.

Isopycnals show a reversal in slope with depth within the channel (but not outside) such that the coldest water is in the west at shallow AABW depths but in the east near the bottom. East of the channel axis there are thick bottom boundary layers which are nearly homogeneous in the vertical but horizontally stratified. We suggest a dynamical, non-mixing mechanism for producing these features.

Dissolved silicate measurements reveal a filament of low concentration, presumably North Atlantic Deep Water, which is located over the channel axis at 2,500 m depth. This is some 1,000 m above the Rio Grande Rise and 2,000 m above the Channel floor.

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OCEAN CIRCULATION

ORIGINS OF THE MEDITERRANEAN OUTFLOW

Harry L. Bryden and Henry M. Stommel

The origin of the Mediterranean outflow is one of oceanography's oldest problems. In this work, the flow of western Mediterranean deep water up and over the sill at Gibraltar is investigated from hydrographic observations and current measurements. The deep water is found to flow westward along the Moroccan

continental slope in the western Mediterranean or Alboran Sea and to rise as it approaches the Strait of Gibraltar. As it enters the Strait, the deep water has potential temperature and salinity characteristics identical to those of newly formed deep water off the southern coast of France, and it is at a depth of 400 m, only 100 m below sill depth. Year-long current meter measurements show the outflow of deep water to be quite steady. The transport of this outflow of western Mediterranean deep water is estimated to be $0.26 \times 10^6 \text{ m}^3 \text{ s}^{-1}$, which is comparable with estimates of its formation rate. This outflow then provides a direct ventilation of the deep water in the western Mediterranean basin.

The deep westward flow along the Moroccan continental slope indicates that the anticyclonic gyre in the Alboran Sea extends throughout the water column. This gyre provides the high velocities necessary to raise the deep water up toward the Strait of Gibraltar. The upward flow of deep water, in turn, provides the source of anticyclonic vorticity necessary to maintain the gyre against frictional dissipation.

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CIRCUMPOLAR CHARACTERISTICS OF BOTTOM AND DEEP WATERS IN THE SOUTHERN OCEAN

Daniel T. Georgi, Alberto R. Piola and Arnold L. Gordon

The distribution and circulation of bottom and deep waters in the Southern Ocean are reviewed with the aid of univariant potential temperature and density histograms and with the aid of horizontal charts of potential temperature and density at 4,000 m. Histograms are given for five regions south of the polar front and for six regions north of the polar front. The southern set indicates that only a minor fraction (one-tenth) of the Antarctic water column is comprised of the extremely cold and dense bottom waters formed near the Antarctic continental margin. The northern set reveals that little bottom water colder than 0°C and denser than $46.10 \sigma_4$ is present in the basins north of the polar front. Only into the Argentine and Crozet Basins do bottom waters colder than 0°C penetrate.

The density histograms for the northern regions generally reveal that a stability maximum in the 45.9 to 45.975 σ_4 density range separates the lighter Circumpolar Deep Waters from the colder and denser lower-Circumpolar Deep Water. The potential temperature/salinity diagram for the 4,000 m level data supports the contention that most of the bottom waters in the Southern Ocean derive from the Circumpolar Deep Waters. The potential temperature/salinity diagram also shows the presence of warmer-saltier water of North Atlantic origin in the South Atlantic and warmer-fresher water of North Pacific origin in the South Pacific.

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EQUATORIAL CURRENTS AT SEMI-ANNUAL PERIOD IN THE INDIAN OCEAN

James R. Luyten and Dean H. Roemmich

Moored records of zonal velocity in the western equatorial Indian Ocean are dominated by motion of semi-annual period. The motion is coherent over an array spanning more than 1,000 km along the equator, 160 km across the equator, and 500 m in the vertical. The signal has an amplitude of .15 m sec⁻¹. It has zonal, vertical and meridional length scales which are long compared to the dimensions of the array, and shows upward propagation of phase. Behavior is characteristic of an eastward propagating equatorial Kelvin wave and a westward long equatorial Rossby wave. The vertical wavelength is an estimated 5,000 m, implying an equatorial trapping scale of 400 km. Zonal wavelengths are about 8,000 km for the equatorial Rossby wave and 24,000 km for the equatorial Kelvin wave. A downward energy flux, estimated to be 3×10^{16} erg sec⁻¹, most likely represents propagation away from surface forcing by the zonal wind.

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RECIRCULATION RECONSIDERED

James R. Luyten and Henry M. Stommel

The ATLANTIS 50°W IGY (International Geophysical Year, 1957-1958) section is used to test ideas about the application of inverse methods to the determination of the absolute geostrophic circulation of the North Atlantic. We argue that the uncertainties in determining the imbalances of relative layer-transport in the deep layers are so great that the heavy weight given them in the Wunsch-Grant charts of absolute circulation yields results that are artificially dominated by bottom topography and are not realistic. We do not dispute the correctness of the formal inverse theory, only the results as given for the particular ATLANTIS section. We offer an elementary explanation for the peculiarity.

Given the magnitude of uncertainty in the relative imbalances it is suggested that they may possibly be insignificant, and that a simple two-point solution for the barotropic velocity can absorb most of them.

When, following Worthington, a balance is sought for a subsection including only the Gulf Stream and the region immediately south of it, the uncertainties in the imbalances of layer transports are less. Application of inverse theory to a schematic representation of this subsection suggests that all possible solutions of the additive barotropic transport are too high to be readily acceptable and that, given his assumption, Worthington's statement that a balanced recirculation across this subsection cannot be obtained is defensible.

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OBSERVATION OF THE CONVECTIVE FORMATION OF THE ANTARCTIC INTERMEDIATE WATER OF THE SOUTH PACIFIC OCEAN

Michael S. McCartney

Late winter measurements in the eastern South Pacific Ocean Subantarctic Zone show convective mixed layers with the correct properties to be the source of the core of the Antarctic Intermediate Water of the South Pacific Ocean. Circulation to lower latitudes occurs by isopycnal advection within a southern intensified anticyclonic gyre.

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THE ONSET OF THE SOMALI CURRENT
DURING 1979: DEVELOPMENT OF
WATER-MASS DISTRIBUTIONS,
PART I: NEAR-SURFACE LAYERS

Robert L. Molinari, John C. Swallow
and John G. Bruce

Hydrographic data in the region of the Somali Current were collected off the east coast of Africa during March to September 1979 to study water mass distributions in time and space, and combined with current observations, to study circulation patterns. Stations were occupied by four ships, DISCOVERY, ISELIN, RESEARCHER and WILKES. Temperature data are accurate to $\pm 0.1^\circ\text{C}$ and salinity data to $\pm 0.1\text{‰}$. The distribution of water masses is characterized by a complicated interleaving of high salinity and low salinity waters. In the near-surface layers (0-200 m), high salinity Arabian Sea water is advected south from the northern Arabian Sea. Low salinity near-surface waters are advected north by the Somali Current. At intermediate depths, the Persian Gulf (at depths ranging from 300 to 350 m) and Red Sea (at depths ranging from 700 to 800 m) serve as source regions for high salinity, low oxygen content waters. The Antarctic (at depths ranging from 700 to 800 m) and Subtropical (at depths ranging from 300 to 400 m) Convergence Zones serve as source regions for low salinity, high oxygen content waters. Interleaving of water masses is observed most frequently below strong surface currents and along salinity fronts and frequently results in salinity extrema on T-S profiles which do not represent water mass core layers in the conventional sense. For instance, a salinity maximum is observed on the $\sigma_\theta = 25$ density surface beneath those stations occupied in or near the Somali Current. The maximum represents a mixing zone between Somali Current and Arabian Sea waters rather than a separate water mass core. Similarly, a deeper salinity minimum is observed between waters formed in the Subtropical Convergence Zone and the Red Sea. This minimum is caused by Red Sea waters replacing Convergence Zone water and does not represent a "true" water mass core. The temporal evolution of the water mass field is shown by distributions of salinity and oxygen on isopycnal surfaces. The distribution of near surface water masses are coupled to the progression to more northerly latitudes of the turn-off position of the northeastward flowing Somali Current and the development of an anticyclonic gyre north of 5°N . The intrusion of the Somali Current is characterized by the northward and eastward extension of low salinity waters from April through July. Much of this water recirculates back south of the equator in a

southwestward offshore flow. The northern gyre from May through July is characterized primarily by high salinity waters which originate in the Arabian Sea. By late August, low salinity Somali Current water has been entrained in the surface layers of the northern gyre. Concurrently, the gyre has shifted south and grown in size. Salinity distributions at 200 m and 700 m show how water advected west by the 200 m and 700 m equatorial jets circulate north and south along the coast.

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CIRCUMPOLAR PROPERTIES OF ANTARCTIC
INTERMEDIATE AND SUBANTARCTIC MODE WATER

Alberto R. Piola and Daniel T. Georgi

Antarctic Intermediate Water and Subantarctic Mode Water are studied by examining their modal density and modal salinity characteristics around Antarctica. The study focuses on fifteen regions in the circumpolar zone between 40°S and 45°S . Circumpolar property distributions for the cores of Antarctic Intermediate and Subantarctic Mode Water and potential temperature/salinity diagrams provide a detailed description of the water masses. The modal salinity and density change gradually across each of the three oceans, presumably due to the alteration of a single water mass. Large modal property changes occur in the transition regions between the oceans: in the Drake Passage, south of Africa and south of New Zealand. Further analysis of these transition regions indicates that the large changes are due to the presence of distinctly different water masses.

Thermohaline finestructure is observed to be associated with these water mass transitions. The finestructure intensity in the depth range defined by the 27.10 and $27.40 \sigma_\theta$ isopycnals is quantified. Although continuous temperature-depth data is not available for the entire circumpolar region, this study indicates that the most intense finestructure is found in regions of large water mass contrast. The finestructure intensity decreases by an order of magnitude away from these regions. Increased vertical-temperature-gradient variances were also observed in the vicinity of a 100 km diameter eddy south of New Zealand.

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NORTH ATLANTIC SUBTROPICAL GYRE: SOFAR FLOATS TRACKED BY MOORED LISTENING STATIONS

Philip L. Richardson, James F. Price,
W. Brechner Owens, William J. Schmitz,
H. Thomas Rossby, Albert M. Bradley,
James R. Valdes and Douglas C. Webb

For the first time SOFAR (sound fixing and ranging) floats were tracked acoustically in the western North Atlantic entirely by means of moored autonomous listening stations. During a five-month period 17 float trajectories were obtained in the eastern (45–65°W) Gulf Stream and subtropical gyre interior at 700 m and 2,000 m depths. These mid-depth trajectories suggest a time-varying Gulf Stream with instances of both a narrow, swift, westward recirculation south of the Stream and a northeasterly penetration into the Newfoundland Basin. A hundred-fold increase of eddy kinetic energy was observed at 2,000 m from the gyre interior (south of 30°N) to the Gulf Stream.

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ON COMBINING SATELLITE ALTIMETRY WITH HYDROGRAPHIC DATA

Dean H. Roemmich and Carl Wunsch

It is shown, by random construction of many sea surfaces, each consistent with geostrophy and mass conservation in the underlying ocean, that absolute sea surface topography can be estimated to 10 cm accuracy from appropriate *in situ* measurements of density. If one desires to use hydrography to remove the oceanographic signal from an altimetric geoid, then 10 cm is the limit of our present capability. If, on the other hand, altimetry is to be used with a gravimetric geoid in order to improve estimates of large scale ocean circulation, then 10 cm is the upper bound on acceptable errors for the combined altimeter and geoid system, over the spatial scales of interest. A hypothetical smoothed altimetric sea surface is used to demonstrate improvement in sea surface estimation in the combined hydrography–altimetry–geoid problem. Linear inverse theory forms the computational framework.

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AN EXAMPLE OF LONG-TERM VARIABILITY FOR SUBSURFACE CURRENT AND HYDROGRAPHIC PATTERNS IN THE WESTERN NORTH ATLANTIC

William J. Schmitz, Jr.
and Michael S. McCartney

An example of long-term variability, perhaps interannual, for current and temperature distributions during mid-1975–1977 along 55°W is presented. The existence of significant energy in the 55°W data set at time scales longer than mesoscale (50–150 days) has been clear for some time, but this is a first description of the latitudinal and vertical pattern of the lowest frequency variability. The pattern observed may be described as a partial meander or lateral shift, or perhaps a contraction of the subtropical gyre, not rigid, associated with changes in water mass properties.

These results are based on two-year duration (nominal) moored current and temperature observations encompassing three array deployments, along with two hydrographic sections made on the setting and retrieval cruises (about nine months apart) for the third array cycle. Each data set spans both the Gulf Stream and its recirculation, the latter mean flow regime being defined here as that immediately adjacent to (offshore), and of opposite zonal flow direction to the former. We also partially sampled the return flow, defined to be the regime offshore of the recirculation, generally weaker in mean and fluctuating current amplitude. The moored instrument observations sample the immediate proximity of the Gulf Stream at 4,000 m depth only, so the hydrographic sections provide the sole information on variations in the upper level Stream as well as in water mass properties.

The long-term average (to suppress mesoscale eddies) current and temperature patterns along 55°W were observed to shift south by about 1.5 to 2 degrees of latitude over approximately an 18-month period. The changes were temporally inhomogeneous. During an initial nine-month (nominal) period, there was a southward shift of about 1 degree of latitude for one segment of the abyssal flow, with a weakening of the westward counterflow under the position of the climatological axis of the Gulf Stream. The location and structure of the recirculation did not vary essentially except in the vertical shear of zonal currents in the thermocline at the boundary of the recirculation and return flow. There was a change in sign of both zonal currents and their vertical shear in the return flow regime. During a second nine-month (nominal) period of observation, the flow pattern offshore of the Gulf Stream

shifted to the south at all depths and the vertical shear of the recirculation increased sharply in the thermocline, with abyssal recirculation becoming weaker as well. The distinction between the recirculation and the return flow became somewhat blurred.

The two hydrographic sections bracketed an interval when the mean zonal currents based on moored instrument data shifted south and increased in vertical shear in the recirculation thermocline. Similar changes occurred between the two hydrographic sections, with the added information that this shift also occurred in the upper level Gulf Stream and was associated with substantial changes in water mass properties. There was an increase in local horizontal temperature gradient in the recirculation regime between the two hydrographic sections, but no noticeable difference in total baroclinic transport (or regional temperature gradient). There was a clear-cut enhancement of the 18 Degree Water thermostat between the hydrographic cruises, which spanned the severe winter of 1976-1977 over the North American continent. This variability was also associated with a significant change in the distribution of salinity anomaly at depths above 2,000 m, along with a smaller scale latitudinal shift relative to the deep current structure in silicate anomaly pattern below this depth. Whereas the current field shifted south, relatively strong salinity anomalies penetrated quite far north, into the Gulf Stream.

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RECENT LONG-TERM MOORED INSTRUMENT OBSERVATIONS IN THE WESTERN NORTH PACIFIC

William J. Schmitz, Jr., Pearn P. Niiler, Robert L. Bernstein and William R. Holland

This note is a description of selected results from the first year's (nominal) deployment, along 152°E from 28°N to 41°N, of an exploratory array of ten moorings with 38 current-temperature meters. The area between the coast of Japan and the Shatsky Rise, for which 152°E is a central longitude, has previously been identified as the most energetic region of the Kuroshio Extension System in terms of upper level thermal variability and geostrophically-estimated (i.e. for velocity differences in the vertical) eddy kinetic energy. Instruments were set in the

thermocline, at intermediate depth, and at an abyssal level on all moorings. On four moorings, current-temperature meters were also scheduled for deployment 200 m up from the bottom and at 250 m depth. The shallower instruments were set even in the immediate vicinity of the Kuroshio Extension, a new sampling initiative, not yet attempted at corresponding proximity to the energetic segments of the Gulf Stream. The new 152°E data are compared with similar observations from other locations in the North Pacific, from analogous regions in the western North Atlantic, and with results from eddy-resolving gyre-scale numerical models.

Eddy kinetic energies along 152°E vary by an order of magnitude or more with latitude at both thermocline and abyssal depths. Abyssal eddy kinetic energies along 152°E near the Kuroshio Extension are a factor of 2 to 3 lower than those previously observed in the immediate vicinity of the energetic regions of the Gulf Stream. However, abyssal kinetic energy levels are comparable at more southerly latitudes, and at 28°N, 152°E, the magnitude and distribution of kinetic energy with frequency along 152°E is similar at 4,000 m depth to that found near 28°N, 70°W. In the thermocline and above at the same location in the North Pacific, distributions of kinetic energy with frequency do not increase with increasing period, in sharp contrast to the situation at 28°N, 70°W. The thermocline kinetic energy frequency distribution at 28°N, 152°E is similar in shape to that observed at a site near 31°N, 70°W, although the total eddy kinetic energy levels are quite different. However, the distance from the corresponding strong current regimes is nearly the same.

Thermocline kinetic energy levels are generally comparable but not identical between the two oceans, at 152°E and 55°W, with the details sensitive to the choice of relative latitude of comparison. Eddy kinetic energy levels along 152°E at 250 m depth (nominal) are about a factor of 3 higher than at 500 m. The 152°E 250 m eddy kinetic energies are comparable with surface estimates near the Kuroshio Extension but lower by a factor of three or four to the south. K_E at 250 m depth (nominal) nearest the Kuroshio Extension is a factor of three or so higher than an estimate for the same depth in the vicinity of the Kuroshio while over the South Honshu Ridge.

Eddy kinetic energy estimates for 152°E near the Kuroshio Extension are compatible with observations over the South Honshu Ridge at a depth of 1,600 m near the Kuroshio and with the results at abyssal

depth near 30°N, 147°E. The maximum 152°E eddy kinetic energy values at 1,200 and 4,000 m (in the vicinity of the Kuroshio extension) are larger than a similar estimate near 2,000 m depth in the vicinity of the Kuroshio west of the South Honshu Ridge by a factor of more than three. As in the North Atlantic the abyssal eddy energy levels near the western mid-latitude jet are much larger than interior values of $1-2 \text{ cm}^2 \text{ s}^{-2}$.

The largest scale latitudinal distribution of horizontal Reynolds' stress has the same general shape (negative to the south and positive to the north of the Gulf Stream or Kuroshio Extension or mid-latitude jet) at all depths for all longitudes where such data are available in both oceans, and in the numerical experiments examined.

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DISTRIBUTION AND CIRCULATION OF LABRADOR SEA WATER

Lynne D. Talley and
Michael S. McCartney

Labrador Sea Water is the final product of the cyclonic circulation of the Subpolar Mode Water in the northern North Atlantic. The temperature and salinity of the convectively formed Subpolar Mode Water decrease from 14.7°C, 36.08‰ to 3.4°C, 34.88‰ due to the cumulative effects of excess precipitation and winter cooling. The coldest Mode Water is Labrador Sea Water, which spreads at mid-depths and is found throughout the North Atlantic Ocean north of 40°N and along its western boundary to 18°N.

A vertical minimum in potential vorticity is used as the primary tracer for Labrador Sea Water. Labrador Sea Water is advected in three main directions out of the Labrador Sea: (1) northward into the Irminger Sea, (2) eastward across the Atlantic beneath the North Atlantic Current, and (3) southward past Newfoundland with the Labrador Current and thence westward into the Slope Water region, crossing under the Gulf Stream off Cape Hatteras.

The Labrador Sea Water core is nearly coincident with an isopycnal which also intersects the lower part of the Mediterranean Water, whose high salinity and high potential vorticity balance the low salinity and low potential vorticity of the Labrador Sea Water. Nearly isopycnal mixing between them produces the upper part of the North Atlantic Deep Water.

A 27-year data set from the Labrador Sea at Ocean Weather Ship BRAVO shows decade-long changes in the temperature, salinity, density and formation rate of Labrador Sea Water, indicating that Labrador Sea Water property distributions away from the Labrador Sea are in part due to changes in the source.

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THE FLUX AND MIXING RATES OF ANTARCTIC BOTTOM WATER WITHIN THE NORTH ATLANTIC

John A. Whitehead, Jr. and
L. Valentine Worthington

Calculation was made of the northward flow of Antarctic Bottom Water into the western North Atlantic Basin through a passageway approximately 300 km wide between the Ceara Rise and the mid-Atlantic Ridge at about 4°N. Two moorings carrying four current meters each were placed in the region where currents were expected to be the greatest, and left for 360 days. The current was not steady, but exhibited large surges with approximately a 60-day time scale whose cause is unknown. Current meters in the fastest flowing region all exhibited a net northward flow. It is estimated that approximately $0.8 \times 10^6 \text{ m}^3 \text{ s}^{-1}$ of water colder than 1.9°C (potential temperature) flowed on the average into the North Atlantic, with this number possibly being too small by $0.3 \times 10^6 \text{ m}^3 \text{ s}^{-1}$ or too big by $0.1 \times 10^6 \text{ m}^3 \text{ s}^{-1}$. However, these numbers differ from geostrophic estimates of $1.98 \times 10^6 \text{ m}^3 \text{ s}^{-1}$, the disagreement coming almost entirely from disagreement of the flux of water colder than 1.2°C. Based upon the two different flux rates, residence times and mixing coefficients are calculated for Antarctic Bottom Water for each 0.1°C potential temperature interval from 1.0°C to 1.9°C. Finally, some comments on the dynamics of the northward flow are made.

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RINGS, EDDIES

SOME DETAILS OF THE COALESCING OF SOMALI
EDDIES DURING THE 1979 SOUTHWEST MONSOON,
A COMPARISON WITH PREVIOUS OBSERVATIONS,
AND A DESCRIPTION OF THE SOCOTRA EDDY

John G. Bruce and William H. Beatty, III

The eddy circulation pattern in the Somali Basin was observed to shift during the latter part of the 1979 southwest monsoon. Measurements were obtained from research vessels, tankers along the standard offshore sea lane and satellite infrared imagery. Initially the current turned strongly offshore between 4°N - 6°N , forming a loop or eddy to the south of the northern or prime eddy which turned offshore at about 10°N . This pattern resulted in two wedges of relatively cold and fresh upwelled water along the coast similar to the type of circulation observed during a 1970 survey. However, by late August the southern turn-off location translated northward and the current then merged and flowed into the northern eddy, producing a relatively fresh and cold cell in the near surface water on the western portion of the northern eddy. By October the circulation appeared to have reverted back to a pattern similar to that during the earlier (June, July) part of the monsoon. The Socotra eddy circulation develops each southwest monsoon approximately between 10°N - 14°N , and during some years its horizontal and vertical scale approaches that of the northern Somali eddy.

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GULF STREAM RINGS

Philip L. Richardson

A summary of Gulf Stream rings is presented which discusses their formation, structure, distribution, movement and lifetimes. Recent observations are described from the 1976-77 cold core ring experiment which shows some of the complexities of rings. Current rings from the Gulf of Mexico, the North Atlantic Current, and other oceans are also mentioned. The main points are: (1) large numbers of highly energetic rings co-exist near the Gulf Stream (and other swift currents); (2) rings (and meanders) are key in causing the peak in eddy kinetic energy near the Stream; (3) rings are thought to be important in transforming and transmitting kinetic and potential energy

within the Gulf Stream System; and (4) ring generation is a dominant means by which water and its physical, chemical and biological components are transferred across the Stream.

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A. R. Robinson, editor.

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A COMPARISON OF THE MID-LATITUDE EDDY
FIELDS IN THE WESTERN NORTH ATLANTIC
AND NORTH PACIFIC OCEANS

William J. Schmitz, Jr.

Latitudinal distributions of estimates of eddy kinetic energy and off-diagonal component of the horizontal Reynolds' stresses are demonstrated to have similar shapes at corresponding locations but much different depths in the mid-latitude North Atlantic and North Pacific Oceans. This comparison is based on direct current measurements at abyssal depths in the North Atlantic along 55°W , and on indirect estimates of upper level velocity differences in the vertical for the North Pacific between the Izu (or Izu-Ogasawara or South Honshu) Ridge and the Shatsky Rise. These sections span the more energetic segments of the Kuroshio Extension and Gulf Stream Systems.

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Oceanography.

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SURFACE LAYER
PROCESSES
AND METEOROLOGYCOMMENTS ON THE WIND FIELD IN THE
WESTERN INDIAN OCEAN AND
RELATED OCEANOGRAPHIC CIRCULATION

John G. Bruce

Monthly wind stress contoured for the western Indian Ocean clearly shows the southwest monsoon from May through September (with values over 4 dynes cm^{-2} during July) to be considerably stronger than the northeast monsoon with a maximum in January. Maps of wind stress curl during the southwest monsoon show a large region of negative curl (over $-4 \times 10^{-8} \text{ dynes cm}^{-3}$) to the northeast off the Somali coast, whereas a region of high positive curl occurs off the Arabian

coast and in a small band off the Somali east coast north of 5°N. Sverdrup mass transports of up to $40 \times 10^{-12} \text{ g sec}^{-1}$ to the north off the Somali coast are in rough agreement with observed values.

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OBSERVATIONS OF THE DIURNAL HEATING IN THE WESTERN EQUATORIAL INDIAN OCEAN

John G. Bruce and William H. Beatty, III

Observations in the northwest Indian Ocean during a windless, sunny day show an increase in the temperature at depths less than 5 m of 2°C to 3°C above that of the upper mixed layer. The heat gain and loss (at night) amounts to about $100 \text{ cal cm}^{-2} \text{ hr}^{-1}$.

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SMALL SCALE SURFACE STIRRING AND FRONTOGENESIS IN THE SUBTROPICAL CONVERGENCE OF THE WESTERN NORTH ATLANTIC

Arthur D. Voorhis and John G. Bruce

Direct observations of surface fronts in the subtropical convergence of the western North Atlantic have been made from rapid and densely sampled XBT (expendable bathythermograph) surveys and by tracking surface drogues. Their rapid formation (one or two days) and the temporal and spatial variation of frontal currents suggests that ageostrophic motions are crucial in the frontogenic process, in agreement with theoretical models. Frontogenesis occurred along the boundaries of small, shallow, but intense cyclones and anticyclones which grew from disturbances along the periphery of a mesoscale cool tongue of surface water of northern origin. The observed scale cascade resembles that due to instabilities in rotating tank experiments, and suggests that this process could be important in lateral stirring and mixing and in releasing the potential energy stored in the upper layers of the subtropical convergence by the large-scale atmospheric forcing.

In press: *Journal of Marine Research*.

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THE RELATION OF NEAR INERTIAL MOTIONS OBSERVED IN THE MIXED-LAYER DURING THE JASIN (1978) EXPERIMENT TO THE LOCAL WIND STRESS AND TO THE QUASIGEOSTROPHIC FLOW FIELD

Robert A. Weller

Oscillations with near inertial frequencies were an energetic component of the upper ocean velocity field observed at each of two moorings separated by 44 km during the Joint Air-Sea Interaction (JASIN) experiment during the late summer of 1978. At each mooring the amplitude of the inertial motion was highest in the mixed layer, where it was nearly depth independent. Previous work had found that the amplitude and phase of inertial motion in the mixed layer was related to the local wind stress. In this case, the local winds, measured at each mooring, were coherent; but the time series of mixed layer near inertial motion at one mooring bore little resemblance to that at the other mooring. During JASIN 1978 the differences in the inertial response at the two moorings coincided with differences in the quasigeostrophic flow field in the vicinity of the two moorings. Inclusion of the horizontal gradients of the quasigeostrophic flow in model equations provides a source of damping and frequency shifting. Divergence in the quasigeostrophic flow damps the inertial motion. Vorticity in the quasigeostrophic flow shifts the frequency of the inertial response to either above or below the local inertial frequency. Upward flow was observed at one mooring as the boundary between two adjacent eddies passed the mooring site, and that observed vertical velocity was used to estimate divergence. Using that divergence, the model equation gave a prediction similar to the inertial response observed at that mooring; both observation and prediction had lower amplitude than anticipated from the observed wind stress.

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THEORETICAL MODELS

PERIODIC AND REGIONAL MODELS

Dale B. Haidvogel

Local dynamical models of the mesoscale eddy field have contributed substantially to our present understanding of the operative dynamical mechanisms in the mid-ocean regions. Here we review two

classes of local eddy-resolving models, the so-called periodic and regional models and how they have been used to investigate the relative importance and dynamical significance of such oceanic factors as non-linear and bottom topographic interactions, planetary vorticity gradients, stratification, local viscous effects, and forcing by the large-scale mean circulation. These studies have identified several important interactions and processes presumed to be operative in the mid-ocean. Examples include the competition between turbulence and waves on a β -plane, the conversion via non-linear interaction of baroclinic to barotropic energy near the Rossby deformation wavenumber and its eventual migration to larger scales, and the role of bottom topography in impeding the tendency towards purely barotropic flow and in generating mean zonal currents by systematic pressure forces associated with bottom roughness. Taking account of all these dynamical mechanisms in combination, periodic models appear to reproduce successfully the statistical dynamical features of the MODE-I eddy field. Regional models, in which the physical and dynamical inhomogeneities associated with the large oceanic gyre are explicitly retained, offer the future possibility of deterministic simulations for these mid-ocean regions.

In press: Eddies in Marine Science,
A. R. Robinson, editor.

Supported by: NSF Grant OCE78-25700.

FINITE-AMPLITUDE BAROCLINIC WAVES AT MINIMUM CRITICAL SHEAR

Joseph Pedlosky

The finite amplitude, inviscid dynamics of a baroclinic wave in the two-layer, β -plane model with y independent basic flow is re-examined. It is shown that at the minimum critical shear where both the potential vorticity gradient and the Doppler shifted frequency vanish within one-layer, there emerges a forced spectrum of harmonics of the basic wave. Although of relatively small amplitude they significantly affect the wave-mean flow interaction mechanism of equilibration. This serves to explain the recent numerical results of Boville. The theory is also extended to discuss the dynamics of a baroclinic wave in a zonal flow which varies in the meridional direction. It is argued that the phenomenon present in the uniform vorticity case, described above, is in fact somewhat peculiar to that case, and that the single wave theory is more generally valid.

In press: Journal of the Atmospheric Sciences.

Supported by: NSF Grant ATM79-21431.

HOMOGENIZATION OF POTENTIAL VORTICITY IN PLANETARY GYRES

Peter B. Rhines and William R. Young

The mean circulation of planetary fluids tends to develop with uniform potential vorticity, q , in regions where closed time-mean streamlines or closed isolines of mean potential vorticity exist. This state is established in statistically steady flows by geostrophic turbulence or by wave-induced potential vorticity flow. At the outer eddy of the closed contours the expelled gradients of q are concentrated. Beyond this transition lies motionless fluid, or a different flow regime in which the planetary gradient of q may be dominant. The homogenized regions occur where direct forcing by external stress or heating within the closed isoline is negligible, upon the potential density surface under consideration. In the ocean such regions lie below the levels of direct wind-induced stress or penetrative cooling. In 'channel' models of the atmosphere the corresponding result predicts regions of constant gradient of q . The gradient may vanish if mesoscale eddies cause the dominant potential-vorticity flux. In the 'real' atmosphere the results here can apply only where internal heating is negligible. The derivations given here build upon the Prandtl-Batchelor theorem which applies to non-rotating, steady two-dimensional flow.

In press: Journal of Fluid Mechanics.

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TURBULENCE AND MIXING, TOPOGRAPHIC EFFECTS

VELOCITY STRUCTURE OF THE BENTHIC OCEAN

Eric D'Asaro

Velocity measurements in the outer part of the bottom boundary layer on the Hatteras Abyssal Plain are examined for indicators of boundary-layer turbulence. Velocity fluctuations in two frequency bands, near-inertial and high-frequency (1-4 cph), display mixed-layer signatures.

The high-frequency velocities measure primarily boundary-layer turbulence. The turbulence, so measured, is modulated on inertial and tidal time scales and extends intermittently to the mixed layer top. The near-inertial velocities are less energetic within the mixed layer than above and, for the dominant clockwise component, the mixed layer leads the interior. This is attributed to turbulent stresses which, consequently, must fill the mixed layer. These observations suggest that the entire bottom mixed layer is at least intermittently turbulent.

In press: Journal of Physical Oceanography.

Supported by: ONR Contract N00014-76-C-0197, NR 083-400; NSF Grant OCE76-81190; and NSF Graduate Fellowship.

TOPOGRAPHIC WAVES ALONG 70°W ON THE CONTINENTAL RISE

Nelson G. Hogg

Moored observations of current and temperature at 15 sites on the continental rise south of Cape Cod are analyzed using the method of "empirical orthogonal functions". The first mode accounts for a majority of the observed variance for motions with periods ranging from 8.3 to 108 days. With a few exceptions the horizontal phase variations and vertical energy decay away from the bottom of this mode are shown to be well described in each of three frequency bands by a simple topographic wave propagating offshore and refracting in response to changes in the environment. The vertical structure at the north end of the array is more complicated and suggests an influence from baroclinic modes possibly generated at the rise-slope transition further to the north.

The horizontal energy distribution is nonhomogeneous and the locations of maxima coincide with calculated ray trajectories and suggest energy propagation along rays from a common source. No source has been conclusively demonstrated but two are suggested: anomalous activity was observed in the surface Gulf Stream in the suspected area for the first few months that the moorings were deployed and, in addition, the mean circulation over the lower rise appears to be unstable to topographic wave disturbances. Implications for the driving of the deep mean circulation are discussed. The observed spatial structure of the Reynolds stresses results from a dispersion of the topographic waves from their common source along different ray paths.

Published in: Journal of Marine Research, 39, 627-649, 1981.

Supported by: ONR Contract N00014-76-C-0197, NR 083-400.

RESONANT TOPOGRAPHIC WAVES IN BAROTROPIC AND BAROCLINIC FLOWS

Joseph Pedlosky

The problem of resonant, topographic, quasi-geostrophic waves is examined analytically by exploiting simplifications that arise when the flow is nearly resonant. The barotropic and (two-layer) baroclinic problems are studied. In each case the topographic linear stability problem is solved explicitly and analytic expressions are given for the growth rate. The bifurcation problem in finite amplitude is also described.

Some differences with earlier treatments are noted. In particular, in the barotropic problem sub-resonant instability may occur if the zonal wave length is long enough. In both the barotropic and baroclinic problems the critical point at which multiple equilibria occur does not correspond to the stability thresholds of the linear problem. In the baroclinic problem Reynolds stresses are found to be of equal importance with eddy heat fluxes in altering the zonal flow although only the latter can transfer energy to the wave field for the zonal velocity profile considered.

Analysis of the marginally stable wave at the minimum critical shear of the ordinary baroclinic stability problem shows that topography is stabilizing.

In press: Journal of the Atmospheric Sciences.

Supported by: NSF Grant ATM79-21431.

W A T E R P R O P E R T I E S

A STANDARD ANALYTIC CURVE OF POTENTIAL VORTICITY VERSUS SALINITY FOR THE WESTERN NORTH ATLANTIC

Laurence D. Armi and Nancy A. Bray

An algorithm is developed which computes salinity as a continuous function of potential temperature for typical western North Atlantic water masses. The curve computed is derived from the potential temperature versus salinity curve

of Worthington and Metcalf for the deep western North Atlantic, and from the temperature versus salinity curve of Iselin for shallow and intermediate waters of the same region. An analytic form for salinity as a function of potential temperature is found by fitting selected points to a cubic spline. The analytic form allows the use of this curve in computations involving continuous profiles of temperature, salinity and pressure.

Supported by: NSF Grants OCE77-19403 and OCE76-81190.

EFFECT OF PRESSURE ON THE PARTIAL EQUIVALENT VOLUME OF SALTS IN SEAWATER

Alvin L. Bradshaw and Karl E. Schleicher

The effect of pressure on the partial equivalent volumes of the major salts in 35‰ seawater at 10° and 25°C was measured for pressures of 400 and 1,000 bars. Partial equivalent compressibilities at atmospheric pressure for these salts were derived.

Supported by: ONR Contract N00014-66-C-0241, NR 083-004.

TECHNICAL REPORTS

A SUMMARY OF WOODS HOLE BUOY GROUP MOORED STATIONS FOR THE POLYMODE PROGRAM

Keith F. Bradley

The Woods Hole Oceanographic Institution Buoy Group's field work for the international POLYMODE program consisted of deployment and recovery of 70 of the 78 program moorings on eight research cruises. The mooring program consisted of four distinct experiments conducted from June of 1974 to November of 1979. A brief description of the arrays is provided, the mooring design process for a typical POLYMODE mooring is explained, and brief summaries are given of the WHOI deployment and recovery cruises. Appendix I is a schematic presentation of the chronological mooring history; Appendix II lists details of the 70 WHOI moorings deployed in the POLYMODE program; and Appendix III lists details of other WHOI moorings that may be of interest to investigators.

WHOI Technical Report 81-15.

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VAX-II PROGRAMS FOR COMPUTING AVAILABLE POTENTIAL ENERGY FROM CTD DATA

Nancy A. Bray

This report documents the WHOI VAX-11 programs used to calculate available potential energy and related quantities from CTD data using the technique described in Bray and Fofonoff (J. Phys. Oceanogr., 11, 30-47, 1981). The report includes examples of how the programs may be used, as well as complete listings of all the required FORTRAN files.

WHOI Technical Report 81-70.

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A COMPILATION OF MOORED CURRENT METER AND WIND RECORDER OBSERVATIONS, VOLUME XXVI (1972 MEASUREMENTS)

Dolores H. Chausse and Richard E. Payne

Summaries of moored current meter and associated oceanographic data collected in 1972 in the Atlantic Ocean by the Woods Hole Oceanographic Institution are presented. The averaged current, wind and temperature data are presented as statistics, progressive vectors, spectral diagrams and vector and scalar plots versus time. The associated hydrographic station data are presented as temperature and salinity plotted against depth.

WHOI Technical Report 81-45.

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TRACKING NEAR SURFACE DROGUES USING AN ACOUSTIC TRAVEL TIME TECHNIQUE IN SHALLOW, HIGHLY STRATIFIED WATER - PROBLEMS AND OBSERVATIONS

James H. Churchill

During July and August of 1980 near surface water velocities of Lake Huron were measured by tracking drogues, equipped with

sonobuoys, using an acoustic travel time technique. Prior to these experiments difficulties associated with acoustic ray bending in the shallow, highly stratified environment were anticipated. Simple models were developed to predict the errors in drogue position and velocity determination resulting from ray bending. During the experiments round trip travel times of acoustic pulses transmitted between three bottom transponders and a transducer (lowered from a ship) were recorded. These combined with ray diagrams strongly suggested that, for a separation between the transducer and a bottom transponder of about 1.2 km, pulses which were detected first traveled by two paths, that of an inflected ray and that of a ray trapped beneath the thermocline. The error in position and velocity determination associated with these paths was one to two percent. Evidence also indicated that increased thermocline depth resulted in decreased tracking range.

WHOI Technical Report 81-37.

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ACOUSTICALLY AND VISUALLY TRACKED DROGUE MEASUREMENTS OF NEARSURFACE WATER VELOCITIES IN LAKE HURON, PLUS OBSERVATIONS OF A COASTAL UPWELLING

James H. Churchill and Berthold H.G. Pade

During July and August of 1980 our research group measured nearsurface water velocities near the eastern coast of Lake Huron by tracking drogues using acoustic travel time and compass sighting techniques. The velocity fields appeared to consist of two components. These have been termed: a sub-current, which varied slowly with depth (compared to the deepest drogue depth of 5.2 m) and, in most cases, was apparently in geostrophic balance with the cross shore pressure gradient; and, a surface layer-current (defined by the relative velocity from deeper to shallower drogues) which decayed rapidly with depth and was directed nearly parallel with the wind and waves. There was no discernible relationship between wind speed and relative velocity. There was, however, a direct dependence of relative velocity with estimated surface roughness, suggesting that Stokes drift may have been primarily responsible for the shear. The magnitudes of the observed relative velocities were approximately equal to Stokes drift magnitudes calculated from representative wave energy spectra. Also reported are measurements of current and temperature structure made prior to and following a coastal upwelling.

WHOI Technical Report 81-91.

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WATER VELOCITY MEASUREMENTS FROM NEAR-SURFACE TO 110 M DEPTH AT DEEPWATER DUMPSITE 106 USING ACOUSTICALLY TRACKED DROGUES AND CONVENTIONAL CURRENT METERS

James H. Churchill, Berthold H.G. Pade and Kenneth R. Peal

A system has been developed recently at WHOI for tracking nearsurface drogues equipped with sonobuoys using an acoustic navigation system. Surface and submerged drogues of mean depths ranging from 0.15 m to 4.88 m were tracked in the vicinity of Deepwater Dumpsite 106. A least squares linear regression technique was used to determine drogue velocities over two-hour periods. Water velocities at depths from 8 to 110 m were measured using a ship-deployed current meter coupled with acoustic tracking of the ship. The results indicated very little velocity shear in the surface mixed layer. There were two regions of strong shear at greater depths, one associated with the main thermocline and the other presumably associated with a halocline.

WHOI Technical Report 81-11.

Supported by: DOE Contract DE-AC02-79EV10005 and NOAA Grant 04-8-M01-62.

PRESSURE, TEMPERATURE, SALINITY AND DISSOLVED-OXYGEN PROFILE DATA FROM R/V ATLANTIS II CRUISE 107 - LEG X

Daniel T. Georgi, Alberto R. Piola and Nancy R. Galbraith

This report summarizes in graphical and tabular form the continuous conductivity-temperature-pressure-dissolved-oxygen (CTDO₂) data collected during the R/V ATLANTIS II Cruise 107, Leg X. These data were collected in the austral winter of 1980 as part of the International Southern Ocean Studies (ISOS) to evaluate and test various Antarctic Intermediate Water formation and circulation mechanisms.

WHOI Technical Report 81-71.

Supported by: NSF Grant OCE78-22223.

A FOUR-DIMENSIONAL PRIMITIVE EQUATION MODEL
FOR COUPLED COASTAL - DEEP OCEAN STUDIES

Dale B. Haidvogel

A prototype four-dimensional (x,y,z,t) continental shelf/deep ocean model is described. In its present form, the model incorporates the effects of finite-amplitude topography, advective nonlinearities, and variable stratification and rotation. The model can be forced either directly by imposed atmospheric windstress and surface pressure distributions, and energetic mean currents imposed by the exterior oceanic circulation; or indirectly by initial distributions of shoreward propagating mesoscale waves and eddies. To avoid concerns over the appropriate specification of "open" boundary conditions on the cross-shelf and seaward model boundaries, a periodic channel geometry (oriented along-coast) is used. The model employs a traditional finite-difference expansion in the cross-shelf direction, and a Fourier (periodic) representation in the long-shelf coordinate. A modified sigma coordinate system, and a Chebyshev-tau approximation scheme, are used to incorporate the vertical dependence. The model has been validated against a variety of propagating topographic wave problems. Representative run times and error estimates are given.

WHOI Technical Report 81-90.

Supported by: NASA Grant NAG 5-8.

A COMPILATION OF MOORED CURRENT-METER
DATA FROM THREE TOPOGRAPHIC EXPERIMENTS:
THE BERMUDA MICROSTRUCTURE ARRAY,
THE ISLAND TRAPPED WAVES ARRAY AND
THE GIBBS FRACTURE ZONE ARRAY,
VOLUME XXVII

Theresa K. McKee, Erika A. Francis
and Nelson G. Hogg

This report is a summary of information collected from three separate oceanographic experiments, each with three moorings, whose objectives were to study the influence of topography on low-frequency motions. Two arrays were set near Bermuda and one in the Charlie-Gibbs Fracture Zone (53°N, 34°W). All the moorings were recovered after nine or thirteen months at sea. Temperature and current velocity data are displayed graphically as time series plots, histograms and spectra. Progressive vector plots and pressure time series are also presented. The data are summarized in statistical tables.

WHOI Technical Report 81-68.

Supported by: ONR Contracts N00014-74-C-0262, NR 083-004 and N00014-76-C-0197, NR 083-400.

A COMPILATION OF MOORED INSTRUMENT DATA
AND ASSOCIATED HYDROGRAPHIC OBSERVATIONS,
VOLUME XXVIII (POLYMODE LOCAL DYNAMICS
EXPERIMENT, 1978-1979)

Carol A. Mills, Susan A. Tarbell
and Richard E. Payne

Summaries are presented of velocities, pressures and temperatures recorded by instruments in the POLYMODE Local Dynamics Experiment (LDE) moored array. The LDE array comprised 28 current meters and 15 temperature-pressure recorders on nine moorings deployed for 15 months in the vicinity of 31°N, 69°30'W from April 1978 to July 1979. Data variables are displayed as time series, histograms, scatter plots, spectra, and in tables of statistics. Summaries of the ten CTD hydrographic stations made on the recovery cruise are also presented.

WHOI Technical Report 81-73.

Supported by: NSF Grant OCE77-19403.

A COMPILATION OF HYDROGRAPHIC STATION
DATA OBTAINED DURING THE 1974-1978
"COBOLT" (COASTAL BOUNDARY LAYER TRANSECT)
EXPERIMENT OFF SHINNECOCK INLET,
LONG ISLAND, NEW YORK

Berthold H.G. Pade

On numerous occasions between 1974 and 1978 field observations on the coastal boundary layer were carried out off Tiana Beach, Long Island, New York. The observational technique employed in the coastal boundary layer surveys was to establish a chain of flag stations anchored at 1 km intervals along a transect perpendicular to the shore, to 12 km from the shore. At these flag stations, daily (weather permitting) temperature, salinity, current speed, and current direction profiles as functions of depth were collected from the R/V COBOLT. This data is computer tabulated and graphically displayed.

WHOI Technical Report 81-9.

Supported by: DOE Contract DE-AC02-79EV10005.

PERFORMANCE CHARACTERISTICS OF
SOME WIND SENSORS

Richard E. Payne

Summaries of performance data on three wind recorder sensor sets are presented: a WHOI-built vane and cup set mounted on a vector averaging current meter (VAWR), a set of standard orthogonal propellers from the vector measuring current meter (VMWR), and an R. M. Young Company utility cup and vane set (Gill). Data were recorded in a wind tunnel and on a dock.

Cup or propeller distance constants were 14.5 m (VAWR), 11 m (VMWR), and 3.5 m (Gill). The VMWR propeller distance constant varied little with azimuth. The VAWR cups had the least sensitivity to tilt, less than 5 percent at 30° compared to 5 percent and 10 percent at 20° for the Gill and VMWR. The Gill and VAWR vanes had delay constants of 1.4 m and 2.6 m, damping factors of .67 and .58, and natural wavelengths of 5.9 m and 10 m, respectively, with some doubt of the VAWR vane figures due to experimental uncertainties.

That the Gill cups had the least overspeeding was apparent even in the vector averaged wind speeds from the dock intercomparisons. In general, the Gill set is capable of recording vector averaged winds on a buoy more accurately than the VAWR or VMWR set although it is not as rugged mechanically.

WHOI Technical Report 81-101.

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DRIFTING VERTICAL CURRENT METER,
MOORED AANDERAA THERMISTOR CHAIN
AND XBT DATA - JASIN 1978
ATLANTIS-II CRUISE (102)

Nancy J. Pennington and Robert A. Weller

The report presents summaries of three data sets taken at and in the vicinity of the oceanographic moorings deployed in the 1978 Joint Air-Sea Interaction Project (JASIN). The data sets are: (1) the temperature, pressure and vertical motion records from the freely drifting Vertical Current Meters (VCMs) deployed from the ATLANTIS II, (2) the temperature data from the Aanderaa thermistor chains on WHOI mooring 653, designated as JASIN mooring W3, and (3) the expendable bathythermograph (XBT) data collected from the ATLANTIS II while participating in the JASIN Project.

WHOI Technical Report 81-92.

Supported by: ONR Contract N00014-76-C-0197, NR 083-400 and NSF Grant OCE77-25803.

WATER SAMPLE AND EXPENDABLE
BATHYTHERMOGRAPH (XBT) DATA FROM
R/V ATLANTIS II CRUISE 107 - LEG X

Alberto R. Piola, Daniel T. Georgi
and Marvel C. Stalcup

This report summarizes the water sample data collected in concert with the continuous conductivity-temperature-pressure-dissolved-oxygen (CTDO₂) data during the R/V ATLANTIS II Cruise 107, Leg X. The hydrographic data consists of up to 24 observations per station of pressure, temperature, salinity, dissolved-oxygen and nutrient content. The report also presents in graphical form the underway expendable bathythermograph (XBT) data. These data were collected in the austral winter of 1980 as part of the International Southern Ocean Studies (ISOS) to evaluate and test various Antarctic Intermediate Water formation and circulation mechanisms.

WHOI Technical Report 81-78.

Supported by: NSF Grant OCE78-22223.

THE BENTHIC BOUNDARY LAYER EXPERIMENT ON
THE HATTERAS ABYSSAL PLAIN: CURRENT AND
TEMPERATURE OBSERVATIONS

Ann Spencer, Eric D'Asaro
and Laurence D. Armi

The near bottom density and velocity fields above the Hatteras abyssal plain were observed with a current/temperature measuring array and a towed-yo-yoing profiler. This report describes the array data and includes details of calibration and data quality. Sources of direction error were diagnosed from vane and compass performance and bearing direction.

WHOI Technical Report 81-12.

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NR 083-400.

MECHANICAL AND OPERATION DETAILS OF A
NEIL BROWN INSTRUMENT SYSTEMS INTERNALLY
RECORDING CONDUCTIVITY, TEMPERATURE, DEPTH
(CTD) PROFILER

Richard P. Trask

The purpose of this report is to discuss the use of a Neil Brown Instrument Systems internally recording CTD. The components of the instrument are described along with the advantages and disadvantages of the internal recording system. Calibration of the pressure and temperature sensors in the laboratory and the method used for in situ calibration of the conductivity sensor are described. A step-by-step description of the use of the CTD/IR at sea is also included.

WHOI Technical Report 81-74.

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MP-1

MARINE POLICY
AND OCEAN MANAGEMENT PROGRAM
David A. Ross, Director

MARINE POLICY and OCEAN MANAGEMENT

OCEAN DISPOSAL OF RADIOACTIVE WASTES:
THE OBLIGATION OF INTERNATIONAL
COOPERATION TO PROTECT THE
MARINE ENVIRONMENT

Daniel P. Finn, Esq.

Radioactive wastes of various forms and levels of radioactivity are regularly released into the marine environment, and ocean disposal may become more important in connection with reprocessing of spent nuclear fuel and disposal of high level waste. Liquid effluents from nuclear power plants and reprocessing facilities are discharged into rivers and coastal waters. Packaged low level wastes are dumped at sea in the deep ocean. High level waste could be disposed of by emplacement in the deep ocean -- on or under the sea floor -- or in mined repositories on islands or the continental shelf.

Ocean disposal of radioactive wastes by one nation may affect the interests of other states in marine resources -- including their sovereign rights in nearshore or exclusive jurisdiction over other coastal resources; their right to reasonable use of high seas resources; and potentially their interest in the seabed beyond national jurisdiction. Reprocessing effluents contain long-lived radionuclides that are transported beyond national zones. A high volume of low level waste dumping could similarly affect high seas resources and even regional coastal resources. High level waste disposal would expose the global ocean to a risk of significant contamination from released wastes, as well as to transportation incidents.

More international attention has been focused on radioactive wastes than any other marine pollutant except oil discharged from vessels. The long history of international cooperation has led commentators to claim that there is a customary law of international cooperation in this field -- requiring at least that states proposing disposal beyond national jurisdiction engage in serious scientific discussion to resolve outstanding technical difficulties in ensuring that human health and marine resources are not significantly affected. This cooperation began with actions by the First United Nations Conference on the Law of the Sea and has proceeded through arrangements made multilaterally or in international organizations. The chief legal instrument is the London Dumping Convention of 1972, under which high level waste dumping is prohibited and other radioactive waste dumping strictly regulated. Important measures have also been taken by the International Atomic Energy Agency, the

Nuclear Energy Agency of the Organization for Economic Cooperation and Development (OECD), and by the OECD Council itself, which has recently adopted a system of prior notification and consultation for sea dumping operations.

Past and current consultations under the above arrangements demonstrate the progressive character of international cooperation on ocean disposal of radioactive wastes. Plans to develop methods of disposing of high level waste at ocean locations will require further international measures. The relationship of the provisions of the London Convention to these activities will have to be clarified or changed. It is unlikely that ocean disposal of high level waste would be politically viable unless strict standards were adopted on an international basis and possibly a new management framework established. Ocean disposal of such wastes -- which would probably occur in areas outside national jurisdiction -- could, however, tend to expedite the development of truly international solutions to the high level waste problem.

Expanded use of the oceans for radioactive waste disposal in connection with nuclear fuel reprocessing and high level waste disposal could affect the entire ocean. It is unlikely that any nation or group of nations could proceed with such activities without resolving the issues of North-South equity in the sharing of the benefits of nuclear technology associated with the reciprocal obligations of the nuclear weapons and non-nuclear weapons stated under the Non-Proliferation Treaty. The international organization encouraged by the nature and history of ocean disposal of radioactive wastes could provide an opportunity to establish institutions, such as international fuel cycle centers, that would help to ameliorate these problems.

In press: Virginia Journal of
International Law.

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Management Program.

WHOI Contribution No. 4849.

INTERNATIONAL COOPERATION TO PROTECT
THE MARINE ENVIRONMENT: THE CASE
OF RADIOACTIVE WASTE DISPOSAL

Daniel P. Finn, Esq.

Packaged low level radioactive wastes
are dumped at sea by several OECD nations

and radioactive effluents from nuclear power plants and reprocessing facilities are discharged into rivers and coastal waters. With the exception of locally high concentrations of radionuclides from reprocessing operations in the United Kingdom, there is little indication of significant radiological effects resulting from current disposal practices. Continued use of the North Atlantic Dump Site, especially at much higher rates, the establishment of new sites, and potential increases in commercial reprocessing could, however, affect man and the economic and social value of living marine resources. Future ocean disposal or storage of high level radioactive waste or spent nuclear fuel by emplacement on or in the continental shelf, deep seabed, or sea islands could expose the global ocean to inputs of long-lived radionuclides as well as the possibility of locally or regionally serious radioactive releases due to transportation accidents or attempted diversion or terrorism.

Considerable international political and technical attention has been accorded to ocean disposal of radioactive wastes since the first United Nations Conference on the Law of the Sea in 1958. The primary international agreement in this field is the London Dumping Convention, in force since 1975. Administrative actions under or related to the London Convention have been taken by the International Atomic Energy Agency (IAEA), the Nuclear Energy Agency of the OECD, and the OECD Council. The potential for increased reliance on the oceans for disposal of radioactive waste -- especially wastes directly generated by the nuclear fuel cycle (spent fuel, high level waste, and chemical wastes from reprocessing) -- calls for continued international cooperation within the current legal and political structure as well as the design of the new institutions. Such institutions will be required to control these more dangerous activities effectively and to resolve outstanding political issues -- especially the issue of international access to and participation in the nuclear fuel cycle. It is to be hoped that the United States will contribute as fully as possible to the international search for solutions to these administrative, technical, and political problems.

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THE MARINE ENVIRONMENT AND MARITIME SECURITY IN SOUTHEAST ASIA: CONTROLLING OIL TANKER TRAFFIC IN THE STRAITS OF MALACCA

Daniel P. Finn, Esq.

In the early 1970s assertion of regional autonomy over control of navigation in the Straits of Malacca appeared to threaten the maritime security of this vital sea route. The resolution to date of the environmental and safety concerns of the coastal states of the Straits -- Indonesia, Malaysia, and Singapore -- illustrates the effective working of international law to resolve the conflicting claims of such coastal states and major outside users. Procedures similar to those used by these coastal states to achieve international recognition for their proposed navigational regulations would be made generally applicable by the Draft Law of the Sea Convention under consideration by the Third United Nations Conference on the Law of the Sea. The international legal procedures used to mediate such conflicts also tend, however, not to arrive at results that are fully satisfactory to all the interests involved. In the case of states bordering international straits, continued attention should be given to their concerns over navigational safety, marine pollution, and local security in order to prevent further conflict between them and outside interests.

In press: Naval War College Review.

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WHOI Contribution No. 4903.

TRACING THE EVOLUTION OF COASTAL ZONE MANAGEMENT

Robert W. Knecht

The evolution of coastal zone management is traced from its beginning in early, pioneering state efforts up to the present, with emphasis on the factors that shaped that development. Of particular interest are the ways in which the coastal management process was influenced by various elements of the Federal CZM program (grants, program approval requirements, federal agencies, etc.). In the decade of the 80s, CZM is likely to be shaped both by the policies of the new administration and the form and urgency of dominant coastal issues. Suggestions are offered as to ways in which some of these policies can be

translated into positive elements in the still evolving CZM process.

In press: Proceedings of the Seventh Annual Conference of the Coastal Society.

Supported by: Pew Memorial Trust; NOAA Grant NA80AA-D-00077 (E/L-1); and the Marine Policy and Ocean Management Program.

THE PANAMANIAN SEA-LEVEL CANAL

Thomas M. Leschine

The history of the debate over the reconstruction of the Panama Canal as a sea-level canal is reviewed. Special emphasis is placed on the debate among marine scientists which grew out of the recommendation in 1970 of the Atlantic-Pacific Interoceanic Canal Study Commission that a new sea-level canal be constructed across the Panamanian isthmus. The repercussions of that debate for the new directions in canal policy now emerging as a result of the Panama Canal Treaties are also discussed. It is concluded that U.S. marine scientists, like their government, are likely to be less influential in future canal reconstruction decisions than they have been in the past.

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THE PANAMANIAN SEA-LEVEL CANAL: PROBLEMS AND PROSPECTS FROM A POLICY PERSPECTIVE

Thomas M. Leschine

The social, political, economic and environmental dimensions of the question of replacing or reconstructing the Panama Canal are discussed. Special reference is made to the effect implementation of the Panama Canal Treaties is likely to have, in light of the recent history of the sea-level canal question. Environmental concerns raised during the past decade are described. The economic benefits of such a canal reconstruction are uncertain, but both costs and benefits appear likely to be spread among an uncommonly large number of interests, partly as an effect of Panama's unique position in the geography of the Americas. The U.S. could do much to assure that important environmental and socioeconomic issues receive proper

attention, despite the diminished role it is likely to have in future canal replacement or reconstruction considerations.

In press: Proceedings of the Joint IEEE-Marine Technology Society Meeting, Oceans 81, Boston, MA, September 1981.

Supported by: Pew Memorial Trust; NOAA Grant NA80AA-D-00077 (E/L-1); and the Marine Policy and Ocean Management Program.

A CRITIQUE OF BENTHOS: A SIMULATION MODEL BY J. R. ALBANESE

Thomas Leschine and Wendell Hahm

A complex generalized simulation model of a marine macrobenthic ecosystem is reviewed and discussed in the context of its potential utility to experimental work at the MERL laboratory at the University of Rhode Island. The MERL (Marine Ecosystem Research Laboratory) experimental system is described and a suite of the most important research questions facing investigators there discussed. The difficulties of using large ecosystem models as an aid to hypothesis-driven ecological research are also discussed. It is concluded that models like BENTHOS may have their best use as heuristic tools able to provide qualitative descriptions of various ecosystem interactions, useful in assessing their potential importance in overall system behavior.

Laboratory Reference Document No. 81-26, National Marine Fisheries Service, Northeast Fisheries Center, Woods Hole, MA.

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RISK REDUCTION IN FISHERIES MANAGEMENT

Susan Peterson and Leah J. Smith

A crucial issue in fisheries management is the extent to which management strategy should be designed to reduce risk: risk of depleting the resource and risk of business failure for the fishermen and processors. Fishery management requires that data be assimilated from a wide variety of sources into a coherent scheme for allocating fish. Many sources of risk, which can be

measured as the probability of an event's occurrence, affect the objectives and outcomes of fishery management strategies. Fishery management decisions are also made in the face of uncertainty, some of which cannot be alleviated by additional information. Four general sources of risk are considered here: the resource and its changing environment; scientific research; markets for the products and factors of production; and management measures. The complexity of fishery management is illustrated through descriptions of interconnected sources of risk, and recommendations for dealing with risk and uncertainty are suggested.

Supported by: Pew Memorial Trust; NOAA Grant NA80AA-D-00077 (E/L-1); and the Marine Policy and Ocean Management Program.

SMALL-SCALE FISHING IN SOUTHERN NEW ENGLAND

Susan Peterson and Leah J. Smith

This description of the small-scale sector of the Southern New England (Massachusetts, Rhode Island and Connecticut) fishery includes information on the fishermen (their ages, education, experience, occupational training, family involvement and reasons for fishing) and the physical characteristics of the fleet (the boats and gear). Fishing patterns are analyzed by species, geographical areas and seasons. The economic structure of small-scale fishing is described in terms of investment, net and gross earnings, fuel costs, crew payments systems and marketing arrangements. Management implications of this information and analyses are included.

WHOI Technical Report 81-72.

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GEORGES BANK: AN ANNOTATED BIBLIOGRAPHY OF ATLASES, INVENTORIES AND MAP SERIES

Richard L. Price

The bibliography reviews inventory-like studies of the Georges Bank region and presents information on the scope of the work, topics treated, geographic area of concern, and audience. The primary purpose was to evaluate the nature and type of maps used in the works reviewed so the notations include the number of maps, their formats and scales, cartographic quality and base map content.

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INSEDIAMENTI MARGINALI NELL'AMBITO DEL TURISMO SARDO (MARGINAL SETTLEMENTS IN SARDINIAN TOURISM DEVELOPMENT)

Richard L. Price

In studies of Sardinian tourism development over the past twenty years little attention has been given to what the author calls "marginal settlements." These are settlements which escape any official recognition, especially in the tourism statistics, as playing a role in tourism on the Sardinian littoral. They include informal seasonal campgrounds, agglomerations of beach cabins, and, most importantly, settlements of rental apartments and second homes. These marginal settlements have a total capacity to house over 200,000 tourists on the Sardinian coast, nearly six times the capacity of the traditional hotels and campgrounds. The author maintains that these settlements should be considered in all phases of tourism development planning, regional planning, and coastal zone management in Sardinia.

In press: Proceedings of the Second International History/Geography Conference on Sardinia in the Mediterranean World, Sassari, Italy, October 1981.

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PLANNING FOR THE PRESERVATION OF SARDINIA'S TOURIST FRINGE

Richard L. Price

Sardinian regional authorities made several attempts to plan for the preservation of the island's coastal environment in the face of massive construction projects and increasing tourism from 1962 to the present. These planning endeavors included attempts to apply national laws to the protection of coastal landscapes and the creation of interim regulations and regional legislation to do the same. Inefficient enforcement of the national laws and

bureaucratic sluggishness at the regional level slowed this planning process considerably.

Published in: "La Consommation d'Espace Par le Tourisme et Sa Preservation," Vol. 2, by the Centre des Hautes Etudes Touristiques, Universite de Droit, d'Economie et des Sciences, Aix-en-Provence, 1981. Proceedings of the meeting of the International Geographical Union's Commission on the Geography of Tourism and Leisure, Aix-en-Provence, September 1981.

Supported by: Pew Memorial Trust; NOAA Grant NA80AA-D-00077 (E/L-1); and the Marine Policy and Ocean Management Program.

MITIGATION, MARSH CREATION AND DECISION-MAKING IN THE COASTAL ZONE

Margaret S. Race and Donna R. Christie

Marsh creation is currently receiving wide attention in the United States as an important tool for mitigating the impacts of development in coastal wetlands. The perception that there is no net loss in valuable coastal wetlands when development is mitigated by the creation of man-made marshes can have a substantial impact on the permitting and decision-making process. The effective result may be the trading of natural salt marshes for man-made marshes.

The techniques for marsh creation were developed by the U.S. Army Corps of Engineers to enhance and stabilize dredge spoil materials. Most research sponsored by the Corps has been directed at determining whether these goals have been accomplished. A survey of the research indicates that there is insufficient evidence to conclude that man-made marshes function like natural salt marshes or provide the important values of natural marshes. It is necessary, therefore, for decision makers to understand the limitations of present knowledge about man-made marshes, realistically evaluate the trade-offs involved, and relegate mitigation to its proper role in the permitting process -- post facto conditions imposed on developments that clearly meet state qualifications and policies.

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WHOI Contribution No. 4999.

REGULATING DRILLING EFFLUENTS ON GEORGES BANK AND THE MID-ATLANTIC OUTER CONTINENTAL SHELF: A SCIENTIFIC AND LEGAL ANALYSIS

Alison Rieser and Judith Spiller

The study is an analysis of issues surrounding the regulation of discharges from oil and gas drilling operations on the Outer Continental Shelf (OCS) with particular reference to the North and Mid-Atlantic regions. It was prepared for the States to assist them in evaluating proposed drilling operations on Georges Bank and future drilling in the Mid-Atlantic. The report consists of a summary of the literature on the fate and effects of drilling mud discharges, a history of the permits which have been issued for exploratory drilling in four OCS regions, and a discussion of issues concerning the monitoring of permit compliance.

A report submitted to the States of Maine, New Hampshire, Massachusetts and New Jersey.

Supported by: Office of Coastal Zone Management, NOAA, and the coastal programs of the States of Maine, New Hampshire, Massachusetts and New Jersey. Contract management handled by the New England River Basins Commission.

MARINE SCIENCE AND THE LAW OF THE SEA

David A. Ross

The present Draft Convention of the Law of the Sea Conference contains restrictions on marine scientific research in about 40 percent of the ocean. Conditions for marine science in internal waters, territorial seas, straits, archipelagos, the exclusive economic zone, the continental shelf beyond 200 miles, and the "area" are discussed. Also presented are some special problems, such as publication rights, and a discussion of implications and recommendations.

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MINING THE DEEP SEABED: A COMPLEX AND INNOVATIVE INDUSTRY

Kurt Michael Shusterich

The high costs, technological uncertainties, and a complicated legal morass have led representatives from United States ocean mining companies to exert pressure on Administration and Congressional leaders in Washington, D.C., to help them secure a favorable operating environment. These efforts have complicated United States relations with many other countries at the Third United Nations Conference on the Law of the Sea (UNCLOS III). This Conference recently received wide publicity because the Reagan Administration dramatically replaced the top United States negotiators in March 1981, and called for a total review of the proposed Treaty. These changes effectively scuttled the possible signing of a Draft Treaty in 1981. The President's actions were welcomed (and influenced) by representatives of the deep seabed mining industry. This article examines the nature, concerns, and interests of that important new industry. (The terms "ocean mining" and "deep seabed mining" are used interchangeably in this article -- they refer specifically to the mining of manganese nodules from the deep seabed.)

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WHOI Contribution No. 5042.

THE MANAGEMENT OF SEA OTTERS AND SHELLFISH FISHERIES IN CALIFORNIA: WHO IS AFFECTED?

Maynard Silva

The protection of the southern sea otter under the auspices of the Marine Mammal Protection Act and the Endangered Species Act has become a controversial issue.

As the southern sea otter has reclaimed portions of its historic range, and as more has been learned about the otters' influence on nearshore communities, it has become evident that other resources and interests have been, or may be, negatively impacted. Just as apparent has been an awareness that the protection of the southern sea otter does, or may, present positive impacts for other resources and interests. The controversy has been expressed in terms of benefits or costs to the affected interests. This paper identifies the relevant resources and

affected groups of the citizenry. In some cases, an indication of the magnitude of the effects is given. These interests include: 1) preservation of the southern sea otter and intrinsic values related to that preservation; 2) commercial fisheries, particularly shellfish fisheries and industries which are associated with these commercial fisheries; 3) recreation and tourism enterprises; and 4) a heterogeneous group of interests which includes the kelp harvesting industry, development of some outer continental shelf hydrocarbon resources, and the United States' balance of trade.

Though uncertainty may exist about the magnitude of some of the costs or benefits, they should nonetheless be considered in any evaluation of management alternatives for protection of the southern sea otter. And if zonal management is adopted, zones should be chosen according to their potential to maximize benefits and minimize costs.

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Conference on Management of Sea
Otters and Shellfish Fisheries in
California: Policy Issues and
Management Alternatives, Arroyo
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THE POLITICAL ECONOMY OF FISHERIES: LESSONS FROM AGRICULTURE

Maynard Silva

Fisheries and agriculture are two industries which share some common features. As a result, comparisons between the two can be made with respect to the outcomes of policy. Extensive federal government involvement with agriculture dates back to the 1930s; with fisheries, federal government involvement has only begun to become extensive in the last decade or so. Thus, analysis of agricultural policy and its outcomes can provide indications of the direction the fishing industry might take as a result of new policies.

Agricultural programs have been of five types: programs to control production, programs of direct assistance, programs to increase demand, programs to differentiate markets, and programs to encourage efficiency. These programs have created income stability for farmers, thereby

creating an investment atmosphere conducive to expansion. Expansion was facilitated by a rapid advance in farm technology -- advances often developed by government funded and/or supported research. The results of this technologically based expansion have included a concentration of farm wealth, a significant undermining of the traditional family farm, and the decline of rural agricultural areas. The losers in this process have been the small- and moderate-scale family farmers -- the very individuals agricultural policy was promulgated to protect. They have been placed at an economic and political disadvantage.

Analysis of recent fisheries policy indicates that they also contain programs to control productivity, give direct assistance, increase demand, and encourage efficiency (there are apparently no programs to differentiate markets). There are some indications that these programs, as in agriculture, are setting the stage for a technological transformation of fisheries by creating a favorable investment environment and by providing the necessary research and development. It is too early to tell if this will lead to a concentration of fisheries capital followed by a dramatic change in the structure and operation of independent fishermen and the decline of rural fishing communities. If it does, government policies will again have worked to the political and economic disadvantage of small- and moderate-sized producers.

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ASSESSING THE EFFECTS OF LIMITED ENTRY INTO FISHERIES: A LONGITUDINAL STUDY OF THE CALIFORNIA ABALONE FISHERY

Maynard Silva, Bilianna Cicin-Sain, Peter Lufkin and John Moore

Limited entry is a fishery management method that is attaining ever increasing attention throughout the world. Although there exist many theories about what limited entry into fisheries is intended (and supposed) to accomplish, very few empirical evaluative data on limited entry have actually been collected or reported. In a review of limited entry experiences around the world completed in 1977, we

concluded that the absence of "pre- and post" empirical data on fisheries to which entry had been limited made it extremely difficult to reach any definitive conclusions about the effectiveness (or lack thereof) of particular limited entry experiences.

This monograph reports the results of a longitudinal study on the effects of limited entry in the California abalone fishery -- a fishery in which limited entry became effective in January 1977. Prior to that time, in 1976, we had conducted a baseline study of the fishery which included interview and mail questionnaire data from all sectors of the fishery, i.e. commercial divers, sports divers, processors, distributors, and resource managers. In 1978-1979, after limited entry had been in effect for approximately two years, we replicated this study in an effort to provide a "before" and "after" perspective. Since limited entry was directed at commercial fishermen, the second phase of the study focused primarily on the commercial sector of the fishery and attempted to follow the fate of those divers who stayed in the fishery as well as those divers who left the fishery in the intervening years. Given the brevity of the interval which elapsed between the first and second waves of the study, it should be emphasized at the outset that our findings cover only the initial or short-term effects of limited entry. Our comments throughout the monograph should thus be viewed as representing tentative and preliminary findings on the ultimate impacts of limited entry.

The monograph is organized in six parts. First, a brief methodological overview is presented. Second, we summarize how the fishery has or has not changed since limited entry was instituted. Third, we focus on the fate of those divers who have left the fishery. Fourth, we discuss the attitudinal changes which have occurred among divers who have stayed in the fishery. Fifth, we review the divers' own evaluations of limited entry. Finally, we conclude by discussing some implications of this case for limited entry proposals elsewhere.

University of California Technical Report.

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FISHERMEN'S EVALUATIONS OF LIMITED ENTRY

Maynard Silva and Biliana Cicin-Sain

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 actual effects of limited entry are currently 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.

The article presents evaluative data on the perceived costs and benefits of limited entry, on the basis of responses from divers who have remained in the fishery, divers who have exited the fishery, processors, and resource managers. We discuss the perceived effects of limited entry on a variety of variables, e.g. the resource, the divers, the price and availability of the product, other fisheries, the consuming public, and the local community. Our findings raise a number of questions about the positive picture of the benefits supposedly adhering to limited entry which the theoretical literature on limited entry has traditionally painted.

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THE PERSONAL AND SOCIAL IMPACTS OF LIMITED ENTRY

Maynard Silva and Biliana Cicin-Sain

This article assesses the personal and social costs and benefits of limited entry focusing on fishermen who have left the California abalone fishery since the establishment of limited entry in 1977. The data reported are based on two surveys -- a baseline study of the fishery conducted in 1976 prior to the inception of limited entry and a second survey conducted in 1979 two years after the establishment of the limited entry program.

Demographic, economic, and attitudinal comparisons are made between divers who have dropped out of the fishery and divers who have remained in the fishery. Patterns of exit from the fishery after limited entry are also compared to drop-out patterns in the fishery prevalent prior to the establishment of the limited entry

system. The article assesses the social costs (e.g., unemployment, geographical dislocation) involved with the displacement of abalone fishermen. Also examined are the personal costs/benefits (e.g., job satisfaction, economic well-being) incurred by those exiting the fishery. A final section discusses implications for other fisheries considering limited entry.

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REGULATING OIL AND GAS ACTIVITIES IN THE FLOWER GARDEN BANKS

Judith Spiller and Alison Rieser

Overlapping regulatory authority and divergent research programs have resulted in inconsistent regulation of hydrocarbon activities at the Flower Garden Banks. Each of the federal agencies involved in developing regulations for the Banks conducts its own research program or requires independent monitoring. Oil and gas industry users, primarily through the American Petroleum Institute, also sponsor research on the fate and effects of drilling discharges. The combination of inconsistent regulations and conflicting research results provides an opportunity for industry and environmental groups to challenge the legitimacy of the regulations. Persons responsible for making similar regulatory decisions for activities in other Outer Continental Shelf areas are confronted, therefore, with a confusing precedent.

This problem could be resolved through the development of a research program designed to produce independently verifiable results. Laboratory investigations that use different techniques and different organisms continue to be conducted. Field studies carried out in the area are an equally frustrating source of information. The hydrodynamics around the Banks are understood to a limited degree. Monitoring studies have followed only one component of the mud and have sampled relatively small areas. Comprehensive data on the current regime around the Banks could provide the basis for modeling the fates of components of the discharge. With these data, predictions about the fate of the discharge could be made. Coupled with information from laboratory investigations, monitoring might then focus on sampling for those effects in

areas where the modeling predicts they will occur. Such a research program requires interagency coordination in conjunction with hypothesis-testing of fates and effects of discharges, which would serve as the foundation for a consistent approach to the regulation of oil and gas activities at the Flower Garden Banks.

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RELATING OCEANOGRAPHY TO ANTILLEAN ARCHAEOLOGY: IMPLICATIONS FROM OCEANIA

David R. Watters

Prehistoric Antillean peoples' cultural adaptations were necessarily based upon orientation toward the sea as well as the land. Terrestrial components have been emphasized in previous archaeological research, yet serious investigation of the maritime aspects of such adaptations is beginning. Wide-ranging interactions between human populations and marine environments are better understood in another insular region, Oceania, and methodologies used, data gathered, and interpretations made there are potentially useful for guiding research in the Antilles. Some peoples seem to be peculiar to the Antilles however, and differences between these areas are as important as the similarities.

Supported by: Pew Memorial Trust; NOAA Grant NA80AA-D-00077 (E/L-1); and the Marine Policy and Ocean Management Program.

LINKING OCEANOGRAPHY TO PREHISTORIC ARCHAEOLOGY

David R. Watters

The disciplines of oceanography and prehistoric archaeology do not broadly interface but instead interrelate through a series of links. Major links (research trends) include (a) maritime adaptations, or the ways prehistoric peoples interacted with the ocean, and (b) post-depositional history, or the ways ocean processes affect the archaeological record. Numerous specific areas of investigation are subsumed within each research trend; areas of investigation and research trends are not mutually exclusive but instead act one upon another.

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ASSESSING THE OCEAN'S ROLES IN ANTILLEAN PREHISTORY

David R. Watters

Archaeologists have not considered adequately either the maritime aspects of cultural adaptations developed by prehistoric Antillean peoples or the impact of ocean processes on the archaeological record. Prehistoric human interaction with the ocean principally occurred in a restricted part of the Caribbean Sea, at the land-sea interface represented by the coastal region and neritic and littoral provinces. It is within these sectors that ocean processes most directly affect archaeological sites. A fuller comprehension of the ocean's roles can be gained by archaeologists through greater awareness of the discipline and subfields of oceanography. Adopting a seaward view, to complement the landward perspective dominant in Antillean archaeology, permits greater understanding of the cultural adaptations developed in the region.

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WHOI Contribution No. 4982.

THE POLITICAL ECONOMY OF SHARED RESOURCES

Per M. Wijkman

This paper considers the problems of efficiently managing common property resources illustrating them by reference to the experiences of international fisheries commissions. Three factors work to maintain some natural resource deposits as shared resources: high risks associated with subdividing resources whose value is uncertain; high costs of subdividing a deposit, of enforcing national sovereignty and of policing private property rights; external economies in exploiting the resource. These factors make exclusive private property rights or national sovereignty inefficient. However, allowing free and open access to the resource results in the "tragedy of the commons" -- overly rapid depletion of natural resource deposits and inefficient use of capital and labor. To prevent this, some form of

management is necessary. Voluntary management may work when firms are few and of equal size, have similar information about the resource and hold similar views of the future. In other cases, government regulation is necessary; when many governments share resource jurisdiction, the management authority must be equipped with coercive powers -- i.e. the power to make decisions which are binding on members, to enforce adherence to these decisions and to refuse access to those who do not comply. The paper argues that the absence of these powers explains the failure of various international fisheries commissions.

gathering or governmental authorities must take sole responsibility for decisions on what information to gather. Efficient remote sensing requires that information be collected when its social value exceeds the costs of collection, that the costs of collection be minimized, and that information be made available to the potentially best user of it.

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COSTS AND BENEFITS OF ALTERNATIVE LEGAL REGIMES FOR REMOTE SENSING

Per M. Wijkman and Clas G. Wihlborg

This paper deals with the equity and efficiency issues involved in alternative legal regimes for remote sensing. This technological innovation in information gathering benefits the international community as a whole because it provides more and cheaper information. However, governments of countries lacking remote sensing facilities fear that the benefits from remote sensing will be unevenly distributed between countries: foreigners may through remote sensing obtain exclusive knowledge which enables them to purchase a resource of the country, or the right to exploit it, at "too low a price." This fear has inspired proposals to regulate internationally the rights to conduct remote sensing.

Our paper considers three legal regimes for remote sensing. Section I analyses proposals by Third World countries for "information sovereignty" in remote sensing. Section II discusses proposals for an international public utility to gather or buy information and disseminate it to users free of charge. Section III considers a global market regime with freedom to do remote sensing and with proprietary rights to remote sensing information. We assume that information is costly to acquire so that either incentives must exist for private firms and individuals to invest in information

GRADUATE STUDENTS

Abstracts of papers and theses submitted in 1981 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.

THE MARINE GEOCHEMISTRY OF THORIUM AND PROTACTINIUM

Robert F. Anderson

Suspended particulate matter was collected by sediment traps deployed in the Sargasso Sea (Site S₂), the north equatorial Atlantic (Site E), the north equatorial Pacific (Site P), and the Panama Basin (STIE Site). Additional samples of suspended particles were obtained by *in situ* filtration at Site E, at the STIE Site, and in the Guatemala Basin. Concentrations of dissolved Th and Pa were determined by extraction onto manganese dioxide adsorbers at Site P, at a second site in the Sargasso Sea (Site D), at the STIE Site and in the Guatemala Basin. Sediment samples were obtained from cores taken near Sites E and P.

Results have shown unequivocally that suspended particulate matter in the open ocean preferentially scavenges Th relative to Pa. This behavior could not have been predicted from the known physical chemistry of Th and Pa. Dissolved ²³⁰Th/²³¹Pa activity ratios were 3-5 at Sites P and D and 3-8 at the STIE Site. In contrast, unsupported ²³⁰Th/²³¹Pa ratios were 22-35 (average 29.7 for 7 samples) in sediment-trap samples from greater than 2000 m at Sites S₂, E and P. Ratios were lower in particulate matter sampled at shallower depths. Particles filtered at 3600 m and 5000 m at Site E had ratios of 50 and 40. In contrast to open ocean samples described above, samples collected by six sediment traps at depths of 667-3791 m in the Panama Basin had unsupported ²³⁰Th/²³¹Pa ratios of 4-8, and the deepest samples had the lowest ratios. Fractionation of Th and Pa that was observed at the three open ocean sites either does not occur or occurs to a very limited extent in the Panama Basin.

Particulate ²³⁰Th/²³¹Pa ratios were negatively correlated with the concentration of suspended particles. However, variable scavenging rates, as indicated by variable particle concentration, do not completely control the ratio at which Th and Pa are scavenged from solution. Major biogenic and inorganic components of trapped material were found in approximately the same proportions in the STIE samples and in samples from Sites E and S₂. Lower ²³⁰Th/²³¹Pa ratios found in the STIE samples must therefore result from subtle changes in the chemical properties of the particles. Consideration of ²³⁰Th/²³¹Pa ratios in several depositional environments indicates that no single factor controls the ratio at which Th and Pa are adsorbed from seawater.

Fluxes of ²³⁰Th and ²³¹Pa were less than their rates of production in the overlying water column in every trap at Sites S₂, E, and P. In the Panama Basin, fluxes measured with the same traps were greater than or equal to their rates of production. These results are a strong indication that even extremely reactive elements such as Th and Pa are redistributed within the oceans. Redistribution occurs because variable scavenging rates in different environments set up horizontal concentration gradients. Horizontal mixing processes produce a net horizontal transport of Th and Pa from areas of low scavenging rates to areas of high scavenging rates. Protactinium is redistributed to a greater extent than Th. Fluxes of ²³⁰Th can be used to set lower limits for horizontal transport of Pa even when absolute trapping efficiencies of the sediment traps are not known. Less than 50% of the Pa produced at the open ocean sites is removed from the water column by scavenging to settling particles. The remainder is removed by horizontal transport to other environments.

At Sites E and P, ²³⁰Th/²³¹Pa ratios were identical in the deepest sediment trap sample and in surface sediments. However, ²³⁰Th/²³²Th and ²³¹Pa/²³²Th ratios were 2.5 times higher in trapped particles than in surface sediments. The ²³⁰Th/²³²Th ratios were 5.5 times higher in particles filtered at 3600 m and 5000 m at Site E than in surface sediments. This observation is best explained by dissolution of most of the Th and ²³¹Pa scavenged by settling particles during remineralization of labile biogenic phases.

The behaviors of certain other radioisotopes were also studied. ²³²Th is present only in detrital mineral components of trapped material. Concentrations of

Th in trapped particles correlate closely with Al and K, at ratios approaching that of average shale or crustal abundances at Sites E and P and basalts at the STIE Site. High specific activities of ²²⁸Th and ²³⁹⁺²⁴⁰Pu were found in sediment trap samples throughout the water column at Sites E and P and in the Panama Basin. The dominant source of these isotopes is near the sea surface and also near the sea floor in the case of ²²⁸Th. Thus it appears that the bulk of the trapped material is recently derived from the sea surface where it incorporates these isotopes, with little loss during rapid transit through the water column. A bioauthigenic form of the deep ocean is 0.25-1.0 dpm/cm²10³ years, which is insufficient to cause a measurable concentration gradient in the uranium concentrations and fluxes of particulate

uranium distribution within the mixing time of the oceans. Increased concentrations and fluxes of particulate uranium were not found in the eastern equatorial North Pacific under areas of an intense oxygen minimum. Therefore, reduction of uranium to the tetravalent state with subsequent scavenging to settling particles in oxygen minima is not a mechanism removing uranium from the oceans.

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MULTICHANNEL MAXIMUM ENTROPY METHOD OF SPECTRAL ANALYSIS APPLIED TO OFFSHORE STRUCTURES

Michael J. Briggs

The multichannel Maximum Entropy Method (MEM) of spectral analysis is developed and applied in the dynamic analysis of offshore structures. Two different algorithms are implemented and computed with the conventional Blackman-Tukey method. These are (1) a direct on the data or Burg method, and (2) a Yule-Walker or correlation function extension method. Cross-spectral estimates of magnitude, phase, coherence squared, and transfer function are calculated. These estimates are then used in mode shape identification of a triple decked, single caisson offshore platform. The superiority of the multichannel Maximum Entropy Methods relative to conventional spectral analysis techniques in calculating these cross-spectral estimates and evaluating mode shapes is demonstrated.

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TRACE ELEMENT GEOCHEMISTRY OF MARINE BIOGENIC PARTICULATE MATTER

Robert W. Collier

Plankton samples have been carefully collected from a variety of marine environments under the rigorous conditions necessary to prevent contamination for major and trace-chemical analysis. Immediately after collection, the samples were subjected to a series of physical and chemical leaching-decomposition experiments designed to identify the major and trace element composition of particulate carrier

phases. Elements examined through some or all of these experiments were: C, N, P, Mg, Ca, Si, Fe, Mn, Ni, Cu, Cd, Al, Ba, and Zn. Emphasis was placed on the identification of trace element/major element ratios in the biogenic materials.

The majority of the trace elements in the samples were directly associated with the non-skeletal organic phases of the plankton. These associations included a very labile fraction which was rapidly released into seawater and a more refractory fraction which involved specific metal-organic binding. Calcium carbonate and opal were not significant carriers for any of the trace elements studied. A refractory phase containing Al and Fe in terrigenous ratios was present in all samples, even from the more remote marine locations. The concentration of this carrier phase within the plankton samples varied in proportion to the estimated rate of supply of terrigenous matter and in opposition to the rate of production of the biogenic particulate matter. The aluminosilicates contributed insignificant amounts to the other trace elements studied. A trace concentration of particulate Al was identified which was more labile and associated with the organic fractions of the samples.

Variations in the surface water concentrations of dissolved Cu, Ni, Cd, and Zn with respect to P are compared to the ratios measured in the plankton samples and their regeneration products. The trace element/major element ratios in the residual plankton materials can be combined with estimates of the carrier fluxes to account for the transport of trace elements required to maintain their deep enrichments.

A variety of processes determining the geochemical cycles of specific trace elements were identified. As much as 50% of the Cd, Ni, Mn, and P are rapidly released from plankton and recycled within the surface ocean. During this process, the metal/P ratio in the residual particles must decrease by 10-30% for Cd and increase by a factor of 2-4 for Ni and Cu to balance their deep enrichments. Although Mn is taken up and regenerated by plankton, the magnitude of this process is small with respect to other non-biogenic Mn fluxes and has very little influence on its dissolved distribution. The Ba content of all known surface carriers is insufficient to account for the deep enrichment of Ba. A secondary concentration process results in the formation of significant particulate Ba within the upper thermocline.

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MECHANISMS OF HEAT TRANSPORT THROUGH THE FLOOR OF THE EQUATORIAL PACIFIC OCEAN

John Crowe

The equatorial Pacific heat flow low, a major oceanic geothermal anomaly centered on the equatorial sediment bulge, was investigated using deeply penetrating heat flow probes (6-11 meters penetration) within three detailed surveys (400 km²) and along over 10,000 km of continuous seismic profiles (CSP). Previous heat flow measurements in this region defined a broad region characterized by a heat flux well below 1 HFU. We report 98 new measurements collected during cruises PLEIADES 3 and KNORR 73-4 that verify the anomalous nature of the heat flux and also define non-linear temperature gradients (concave down). Temperature field disturbances due to perturbations of a purely conductive heat transport regime are incapable of suitably explaining either of these observations. A simple model incorporating heat transport by both conduction and fluid convection through the sediments fits the observations. A volume flux of (hydrothermal) fluid in the range of 10⁻⁶ to 10⁻⁵ cm³/sec/cm² (0.1 liter/yr/cm²) is required. The sense of the flow for all measurements exhibiting non-linear gradients is upward out of the sediment column; no evidence for the recharging of the system was observed.

Investigation of a well-defined boundary of the low zone at 4°N and 114°W showed a transition from low and variable heat flow to values compatible with thermal models that correlated with a change in the nature of the basement from rough to smooth. A few outcrops occur in the area of rough basement, but otherwise the region is well-sedimented (greater than 200 meters). Measurements within a detailed survey centered at this transition showed a dramatic increase in heat flow from 1.21 HFU to values greater than 3 HFU over a horizontal distance of 10 km. A similar transition from non-linear to linear temperature gradients was not observed as nearly every measurement was non-linear.

Heat flow measurements located in well-sedimented, outcrop-free areas (A environments) were associated with linear gradients and a heat flux greater than 1 HFU. However, several of these values were well below the theoretical heat flow for

the appropriate age crust. Values measured in environments other than A exhibited variable heat flow and non-linear gradients. The average value of measurements located in A environments within the equatorial Pacific heat flow low was 1.37±0.27 HFU. The previously reported average was 0.92±0.48 HFU based on several measurements from LDGO cruise VEMA 24-3.

The average heat flow measured at a survey located outside the low heat flow zone on crust of 55 ±5 m.y. was 1.76 ±0.30 HFU which is in good agreement with the theoretical value of 1.60. The measurements in this survey were not located in A environments suggesting that crustal convection has ceased or is greatly attenuated within crust of this age.

Error analysis of the geothermal data reduction using the convective/conductive heat transport model suggests that the volume flux parameter is sensitive to temperature measurement errors greater than a few millidegrees. Volume fluxes less than 10⁻⁷ cm/sec are difficult to distinguish from the purely conductive case assuming instrumental accuracies of 0.001°C. Resolution of the volume flux deteriorates as heat flow decreases and is poor for values less than 0.5 HFU. A detailed survey located within the low zone confirmed previous measurements of low heat flow. However, due to the low value of heat flow (about 0.5 HFU), the small-scale variability could not be clearly defined.

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ASSIMILATORY SULFUR METABOLISM IN MARINE MICROORGANISMS

Russell L. Cuhe

The reductive assimilation of sulfate into cellular organic sulfur compounds was studied in aerobic marine bacteria, with emphasis on the relationship between sulfur metabolism and protein synthesis. The goal of the study was to develop and apply a method for the quantitative assay of total bacterial protein synthesis in aerobic ocean waters. The study consisted of four parts:

- (1) The sulfate transport systems of two nutritionally different marine bacteria, *Pseudomonas halodurans* and *Alteromonas luteo-violaceus*, sulfate were characterized to provide information on environmental regulation of sulfate transport capacity. In common with terrestrial bacteria, the transport systems of both marine bacteria exhibit (a) size-selective competitive inhibition of sulfate uptake by sulfate analogs, (b)

requirements for energy coupling, and (c) derepression of transport capacity as a result of sulfur starvation. Features which are unique to the marine bacteria include (a) a ten-fold lower affinity for sulfate (half-saturation constant $\sim 200 \mu\text{M}$), (b) derepression of transport capacity when grown with methionine as the sole source of sulfur, and (c) an inability to accumulate inorganic sulfate in excess of growth requirements. The different characteristics of the sulfate transport systems of the marine bacteria relative to terrestrial microorganisms are consistent with the saturating concentration of sulfate that is always present in their environment. Substantial differences also exist between the two marine bacteria, notably in the effect of thiosulfate on sulfate uptake. *P. halodurans* transports thiosulfate with a ten-fold higher affinity than sulfate. Sulfate and thiosulfate are mutually competitive inhibitors of transport, and the half-saturating concentration of thiosulfate for uptake also produces half-maximal inhibition of sulfate transport. Sulfate and thiosulfate transport systems both respond similarly to all inhibitors. These facts implicate a common carrier for the two compounds. In contrast, sulfate transport in *A. luteo-violaceus* is relatively insensitive to thiosulfate. The effect of the sulfhydryl reagent pHMB is similarly much less pronounced than in *P. halodurans*. These and other differences indicate that the sulfate transport system of *A. luteo-violaceus* is unique among microorganisms.

(2) Growth experiments with *P. halodurans* and *A. luteo-violaceus* were carried out over a range of nutritional regimes. Biomass parameters (cell counts, bulk protein, particulate carbon and nitrogen), total uptake of radioactive sulfate, and the distribution of sulfur in major biochemical components (low molecular weight [L.M.W.], alcohol soluble protein, lipid, hot TCA soluble material, and residue protein) were monitored to determine the variability in cellular composition as a function of the environment. Special emphasis was placed on the quantitative relationship between incorporation of sulfur into protein and bulk protein synthesis and conditions which might alter the sulfur content of protein. It was found that sulfur metabolism is restricted predominantly to the production and utilization of protein precursors. The protein synthesis inhibitor chloramphenicol caused an immediate halt to both bulk protein synthesis and sulfur incorporation into protein, accompanied by a rapid swelling of L.M.W. organic sulfur pools, in both bacteria. Incorporation of exogenous sulfur into protein was rapid due to the very small size of the L.M.W. pool. No

significant deviation from the ratio of protein-S:bulk protein determined for unperturbed exponential growth was observed as a function of carbon limitation, nitrogen limitation, treatment with chloramphenicol, or during lag and stationary phases. However, the concentration of sulfate in the growth medium exerted a strong influence on the sulfur content of both whole cells and isolated protein. At concentrations less than $500 \mu\text{M}$ (*P. halodurans*) or $100 \mu\text{M}$ (*A. luteo-violaceus*) the weight percent S in protein was proportional to the sulfate concentration in the medium. Since the sulfate concentration is invariably high in seawater (25mM), data from sulfur-limited growth were not included in the analysis of compositional variability. Under all the conditions examined, the incorporation of sulfur into protein provided the best measurement of protein synthesis and cell growth, with a very low coefficient of variation for the protein-S:bulk protein ratio (less than 16 percent). The mean true weight percent S in protein, 1.07 (*P. halodurans*) and 0.92 (*A. luteo-violaceus*) agrees well with the 1.1 percent predicted from analyses of sequenced proteins.

(3) The method used for the analysis of sulfur incorporation into protein was tested with mixed natural populations of marine bacteria in enrichment culture and 13 isolates from the Sargasso Sea to establish the variability of the protein-S:bulk protein ratio among marine bacteria. The mean true weight percent S in protein, 1.09, and the operational weight percent S in protein, 0.93, have coefficients of variation of 13.1 and 15.1 percent, respectively. The values are similar to those obtained with the two marine bacteria studied in detail and to that predicted from protein composition studies. Therefore sulfur incorporation into protein measures protein synthesis in marine bacteria within a small degree of error.

(4) The method was applied to unenriched natural populations of marine bacteria in waters of the continental shelf, slope, and Sargasso Sea. Time-course incorporation measurements revealed a long lag period at the shelf and slope stations, whereas incorporation of sulfur into protein began immediately in the Sargasso Sea. However, long term incubations confirmed that the potential for bacterial protein synthesis decreases in an off-shore transect. These observations were confirmed by simultaneous incorporation studies using labeled ammonia, phosphate, and organic carbon compounds.

The potential protein synthesis measured in the unenriched samples provides

evidence suggesting that bacterial biomass may be an important contributor to marine food webs.

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THE DYNAMICS AND KINEMATICS OF THE COASTAL BOUNDARY LAYER OFF LONG ISLAND

Neal R. Pettigrew

Data from the COBOLT experiment, which investigated the first 12 km off Long Island's south shore, are analyzed and discussed. Moored current meter records indicate that the nearshore flow field is strongly polarized in the alongshore direction and its fluctuations are well correlated with local meteorological forcing. Complex empirical orthogonal function analysis suggests that subtidal velocity fluctuations are barotropic in nature and are strongly influenced by bottom friction.

Wind-related inertial currents were observed within the coastal boundary layer (CBL) under favorable meteorological and hydrographical conditions. The magnitude of these oscillations increases with distance from shore, and they display a very clear 180° phase difference between surface and bottom layers. Nearshore inertial oscillations of both velocity and salinity records appear to lead those further seaward, suggesting local generation and subsequent radiation away from the coast.

The response of the coastal zone to impulsive wind forcing is discussed using simple slab and two-layer models, and the behavior of the nearshore current field examined. The major features of the observed inertial motions are in good qualitative agreement with model predictions. It is found that, in a homogeneous domain, the coastal boundary condition effectively prohibits inertial currents over the entire coastal zone. In the presence of stratification the offshore extent of this prohibition is greatly reduced and significant inertial currents may occur within one or two internal deformation radii of the coast. The "coastal effect", in the form of surface and interfacial waves which propagate away from the coast, modifies the "pure" inertial response as it would exist far from shore. The kinematics of this process is such that a 180° phase difference between currents in the two layers is characteristic of the entire coastal zone even before the internal wave has had time

to traverse the CBL. It is also suggested that, for positions seaward of several internal deformation radii, interference between the surface and internal components of the coastal response will cause maximum inertial amplitudes to occur for $t > x/c_2$, where c_2 is the phase speed of the internal disturbance.

The hydrographic structure of the CBL is observed to undergo frequent homogenization. These events are related to both advective and mixing processes. Horizontal and vertical exchange coefficients are estimated from the data, and subsequently used in a diffusive model which accurately reproduces the observed mean density distribution in the nearshore zone.

Dynamic balance calculations are performed which indicate that the subtidal cross-shore momentum balance is very nearly geostrophic. The calculations also suggest that the longshore balance may be reasonably represented by a steady, linear equation of motion which includes surface and bottom stresses.

Evidence is presented which shows that variations in the longshore wind-stress component are primarily responsible for the energetic fluctuations in the sea surface slope along Long Island. Depth-averaged velocities characteristically show net offshore transport in the study area, and often display dramatic longshore current reversals with distance from shore. These observations are interpreted in terms of a steady circulation model which includes realistic nearshore topography. Model results suggest that longshore current reversals within the CBL may be limited to the eastern end of Long Island, and that this unusual flow pattern is a consequence of flow convergence related to the presence of Long Island Sound.

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THE VERTICAL STRUCTURE OF THE WIND-DRIVEN CIRCULATION

William R. Young

This thesis consists of three loosely related theoretical studies.

In chapters 1 - 3 the physical mechanisms which determine the three dimensional structure of the currents in the Sverdrup interior of a wind-driven gyre are discussed. A variety of simple analytic models suggest that the subsurface geostrophic contours in a wind gyre are closed and so the flow in these regions is not determined by lateral boundary

conditions. Instead a turbulent, quasigeostrophic extension of the Batchelor-Prandtl theorem suggests that the potential vorticity is uniform inside these laterally isolated regions. The requirement that the potential vorticity be uniform leads simply and directly to predictions of the shape and extent of the wind gyre and the vertical structure of the currents within it.

In chapter 4 the propagation of Rossby wave trains through slowly varying forced mean flows is examined by solving the linearized potential vorticity equation using the WKB method. If the mean flow is forced the action defined by Bretherton and Garrett (1968) is not conserved. Surprisingly, there is another quadratic wave property which is conserved, the wave enstrophy.

In chapter 5 shear dispersion in an oscillatory velocity field, similar to that of an inertial oscillation, is discussed. The goal of this section is to develop intuition about the role of internal waves in horizontal ocean mixing. The problem is examined using a variety of models and techniques. The most important result is (23.2), which is an expression for the effective horizontal diffusivity produced by the interaction of vertical diffusivity and oscillatory vertical shear. Given an empirical velocity shear spectrum and an estimate of the vertical diffusivity this result could be used to calculate a horizontal eddy diffusivity which parameterized the horizontal mixing due to the internal wave field.

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