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Arthur E. Maxwell

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Preface

This is the third year the Institution has collected and printed together abstracts of all papers submitted for publication during the calendar year. Success in the project can be measured by noting that the preceding two volumes are out of print. Such demand has encouraged us to continue the endeavor.

As has been noted before, this series is a continuation in slightly different format of the Summary of Investigations, which was circulated by the Institution for thirteen years. It is intended to provide the reader with timely and concise information concerning research activities recently completed within the Institution.

All abstracts have been included, as far as possible, without editorial change, as submitted by the Department Chairmen and the Dean of Graduate Studies. Since the papers from which the abstracts have been taken may not be published in the journal to which they have been submitted initially, we have intentionally omitted identifying the journals. The volume is not intended to be a bibliography.

Hopefully, the two-column per page layout will make reading easier than before. I am grateful for Mary Thayer's efforts in making this a successful series.

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Arthur E. Maxwell

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BIOLOGY

DEPARTMENT OF BIOLOGY

George D. Grice, Department Chairman

AQUACULTURE

PRELIMINARY STUDIES ON A COMBINED SEAWEED
MARICULTURE-TERTIARY WASTE TREATMENT SYSTEMJames S. DeBoer, Brian E. Lapointe
and John H. Ryther

A pilot-plant scale waste recycling-mariculture system was developed at the Woods Hole Oceanographic Institution's Environmental Systems Laboratory in 1973. Basically, the concept of this system is to grow unicellular marine algae in continuous flow cultures on mixtures of seawater and secondarily treated sewage effluent, and feed the algae to bivalve molluscs, maintained in a separate culture system. A final polishing step in the system consists of macroscopic algae (seaweeds) which remove the dissolved nutrients regenerated by the animal culture prior to discharge of the final effluent. In addition to serving as final polishing step in the phytoplankton-shellfish waste recycling system, seaweeds are also used as a one-step waste recycling-mariculture system.

Supported by: *Jessie Smith Noyes Foundation*; NOAA, Office of Sea Grant 04-6-158-44016; ERDA Contract E(11-1) 2948.

POTENTIAL YIELDS FROM A
WASTE RECYCLING-ALGAL MARICULTURE SYSTEM

James A. DeBoer and John H. Ryther

Gracilaria sp. and *Neogardhiella baileyi* were grown in tertiary waste treatment-poly-culture and monoculture systems. Maximum yields were obtained when the seaweed density was maintained within the range of 1800-2800 g fresh weight/m² during the winter and 2800-4500 g/m² during late spring and summer. Growth rate increased with increasing nitrogen concentration up to approximately 0.8 μ M ammonium. Little increase in growth rate occurred at higher ammonium concentrations. Phyco-colloid content was highest at nitrogen concentrations of approximately 0.5-1.0 μ M ammonium and decreased at higher nitrogen concentrations. The application of these results to the cultivation of macroscopic marine algae is discussed.

In press: *The Marine Plant Biomass of the Pacific Northwest - A Potential Economic Resource*. Oregon State University.

Supported by: NOAA Sea Grant 04-6-158-44016; ERDA Contract E(11-1) 2948; and *Jessie Smith Noyes Foundation*.

STUDIES ON THE CULTIVATION OF MACROSCOPIC
RED ALGAE. I. GROWTH RATES IN CULTURES
SUPPLIED WITH NITRATE, AMMONIUM UREA,
OR SEWAGE EFFLUENTJames A. DeBoer, Harry J. Guigli,
Thomas L. Israel and Christopher F. D'Elia

Gracilaria foliifera (Forsskal) Børgesen and *Neogardhiella baileyi* (Harvey ex Kutzing) Wynne and Taylor were grown in continuous-flow culture under controlled environmental conditions in 15-liter experimental chambers. Growth rate was related to the source and concentration of nitrogen enrichment supplied to the plants. Growth rate appeared to follow saturation-type nutrient uptake kinetics for plants receiving ammonium, nitrate, urea, or sewage effluent enrichments. Ammonium enrichment produced higher growth rates than nitrate or sewage enrichment. The lowest growth rates occurred in the chambers receiving unenriched seawater or urea enrichment. Half saturation constants (K) for growth were in the range of 0.2 to 0.4 μ M nitrogen for all nitrogen enrichments examined. The low values of K measured compare closely to those found for microalgae and indicate that *G. foliifera* and *N. baileyi* possess the ability to utilize very low concentrations of nitrogen.

Supported by: ERDA Contract E(11-1) 2948 and *Jessie Smith Noyes Foundation*.

STUDIES ON THE CULTIVATION OF MACROSCOPIC
RED ALGAE. II. KINETICS OF AMMONIUM
AND NITRATE UPTAKE

Christopher F. D'Elia and James A. DeBoer

The ammonium and nitrate uptake kinetics of *Neogardhiella baileyi* (Harvey ex Kutzing) Wynne and Taylor and *Gracilaria foliifera* (Forsskal) Børgesen were studied. Similar kinetic patterns were observed for both Rhodophyceans. Nitrate is taken up in a rate-saturating fashion that can be described by the Michaelis-Menten equation. Ammonium uptake is multiphasic: in addition to a saturable component, there is a diffusive or a high K component which shows no evidence of saturation at the highest concentrations tested (ca. 50 μ M).

Nitrogen starved plants, i.e., those with C/N ratios (by atoms) exceeding 10-11, show much higher transient rates of ammonium uptake at a given concentration than do plants which are not nitrogen limited. Only plants with high nitrogen content exhibit diel changes in ammonium uptake rates, and show transient rates of ammonium accumulation which do not far exceed the capacity to incorporate nitrogen in steady-state growth.

There is a strong preference for ammonium over nitrate, even in plants preconditioned on nitrate as the sole nitrogen source. Nitrate uptake is suppressed at ammonium concentrations exceeding 5 μM , but below that concentration simultaneous uptake of both is possible at unsuppressed rates. At higher substrate concentrations increasingly more nitrogen can be accumulated via ammonium uptake than can be accumulated via nitrate uptake.

Changing capacity for ammonium uptake with nitrogen content appears to be a mechanism whereby excessive assimilation of nitrogen is avoided by the plants under conditions of nitrogen satiation, or whereby large amounts of ammonium-N can be rapidly assimilated under conditions of nitrogen privation.

Supported by: ERDA Contract E(11-1) 2948
and Jessie Smith Noyes Foundation.

MASS PRODUCTION OF ALGAE:
BIOENGINEERING ASPECTS

Joel C. Goldman and John H. Ryther

The concept of mass culturing freshwater and marine algae for subsequent harvesting, fermentation, leading to methane production for use as an energy source is currently under intensive research. A major difficulty with this concept, as is true of all solar energy collecting schemes, is that the flux of solar energy striking the earth is low, hence necessitating the use of large and elaborate collection systems. Algal systems, in addition to requiring very large tracts of land, require tremendous quantities of nutrients and water. Thus, the only feasible algal systems for energy production are those utilizing recycling of materials. An energy balance for such systems does not appear to be favorable, given the projected average yield of 10 gr dry wt/m²/day that appears to be a reasonable design assumption based on existing mass culture data. Wastewater treatment, food production, aquaculture and chemicals production, all on a much smaller scale than the envisaged energy systems may be the most advantageous and energy-efficient uses for algal mass cultures.

In press: "Biological Solar Energy Conversion", Academic Press, 1977.

Supported by: ERDA Contract EG-77-5-02-4151.

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

Brian E. Lapointe and John H. Ryther

A series of outdoor, continuous-flow seawater cultures (50 liter; 0.23 m²) were used

to investigate the effects of culture density (kg/m², nutrient loading (total nitrogen input/day) with both NH₄⁺-N and NO₃⁻-N, and turnover rate (flow rate/culture volume) on the growth and yield of *Gracilaria foliifera* v. *angustissima* (Harvey) Taylor (Gigartinales). Although specific growth rates as high as 60% per day were recorded for *Gracilaria* at low densities (0.4 kg wet wt/m²) in summer conditions, maximum year-round yields were obtained at densities of 2.0-3.0 kg wet wt/m². Above a minimal daily nitrogen loading, yield of *Gracilaria* was independent of nutrient concentration, nitrogen loading or whether nitrogen was in the form of NH₄⁺-N or NO₃⁻-N but was highly dependent upon flow rate. The time weighted mean annual production during 1976-77 was 34.8 dry wt/m²/day or 127 metric tons/hectare/year based on 12 months continuous operation at near optimal densities and flow rates in the non-nutrient limited culture system.

Presented at: International Seaweed Symposium, Santa Barbara, California.

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Jessie Smith Noyes Foundation.

THE EFFECTS OF NITROGEN AND FLOW RATE ON
THE GROWTH AND COMPOSITION OF
Gracilaria foliifera V. *angustissima*
(HARVEY) TAYLOR IN MASS OUTDOOR CULTURE

Brian E. Lapointe and John H. Ryther

A series of outdoor, continuous-flow seawater cultures (50-l) were used to investigate the effects of nitrogen form (NO₃⁻ vs. NH₄⁺, nitrogen loading (total nitrogen input per day) nitrogen concentration and water turnover rate on the growth and composition of *Gracilaria foliifera* v. *angustissima* (Harvey) Taylor (Gigartinales). Both nitrogen assimilation and algal growth were to nitrogen loading and found independent of nutrient concentration. Above a minimum nitrogen loading of between 9 and 15 m moles/day algal growth was highly dependent upon turnover rate. Levels of stored inorganic nitrogen ranged from 0.5 μ mole/g dry wt in slow growing, nitrogen-limited plants to 5 μ mole/g dry wt in slow growing, nitrogen-enriched plants. Growth of *Gracilaria* was better with NH₄⁺-N than NO₃⁻-N at nitrogen loadings that were just adequate to support exponential growth. However, at higher levels of nitrogen loading, the greatest yields (up to 44 g/dry wt/m²/day) occurred with NO₃⁻-N rather than NH₄⁺-N possibly due to toxic effects of the latter. Percent of dry weight and ash of *Gracilaria* was highly correlated with nitrogen content of the plant and affected the heat of combustion of the alga in a similar fashion. Although levels of both phycoerythrin and chlorophyll increased with increasing nitrogen content of the plant, phycoerythrin/chlorophyll ratios did not change

substantially and suggests that nitrogen-related pigment changes in *Gracilaria* are light intensity and not light quality adaptations. The use of carbon/nitrogen ratio as an index of the nutritional state of *Gracilaria* (and probably other seaweeds) appears to be a useful tool in understanding its growth and composition and should be considered in ecological investigations concerning seasonal patterns of seaweed biochemistry and their relation to herbivore and detritivore food chains.

Supported by: ERDA Contract E(11-1) 2948.

SOME BIOCHEMICAL AND PHYSIOLOGICAL ASPECTS OF GROWTH AND GAMETOGENESIS IN Crassostrea gigas (Thunberg) and Ostrea edulis L. Grown AT SUSTAINED ELEVATED TEMPERATURES

Roger L. Mann

Crassostrea gigas (Thunberg) and *Ostrea edulis* L. were grown at sustained temperatures of 12, 15, 18 and 21°C for a period of 19 weeks. Regular assays of weight specific ammonia excretion rate were made following which animals were sacrificed for estimation of dry meat weight, dry shell weight, biochemical composition (percentage carbon, nitrogen, carbohydrate, ash) and gonadal development (histological assessment). *C. gigas* grew from an initial live weight of 5.2 gm to values of 23.5, 28.2, 34.6 and 38.7 gms at 12, 15, 18 and 21°C respectively. However, dry meat increment was not positively related to temperature. An initial value of 88.7 mg, and terminal values of 1736.0, 1253.0, 1322.0 and 1219.0 mg were recorded at 12, 15, 18 and 21°C respectively. *O. edulis* exhibited an increase in both live and dry meat weight proportional to experimental temperature with live weight increasing from 4.08 to 22.3 gm and dry meat weight from 95.0 to 756 mg over the experimental period at 21°C.

An initial increase in percentage carbohydrate was observed at all temperatures in both species. In *C. gigas* this was followed by a subsequent decrease which was closely related to the late active stage of gametogenesis. The transition from increasing to decreasing percentage carbohydrate content occurred earlier at higher temperatures. In *O. edulis* no marked decrease was noted in percentage carbohydrate content despite marked gametogenic activity. No evidence of hermaphroditism was found in *C. gigas*. 27% of *O. edulis* examined contained sex products of both sexes at various stages of development. Ripe gonads developed in both species at all temperatures, however, *C. gigas* spawned only at 18 and 21°C, and *O. edulis* spawned at 15, 18 and 21°C. Ammonia excretion data exhibited an allometric relationship ($E = aw^b$)

with weight prior to spawning in both species at all temperatures. Post spawning an increase in weight specific excretion rate was observed. These data did not fit an allometric relationship with weight.

Supported by: Jessie Smith Noyes Foundation and NOAA Sea Grant 04-6-158-4406.

GROWTH OF Mytilus edulis L. IN A WASTE RECYCLING AQUACULTURE SYSTEM

Roger L. Mann

The mussel, *Mytilus edulis*, was grown in a waste recycling aquaculture system at 14°C on a diet of *Phaeodactylum tricornutum* and *Skeletonema costatum* cultured in a 15% sewage-seawater mixture. Mussels exhibited a 116% increase in mean live weight (5.5 to 11.9 gm), a 718% increase in mean dry meat weight (0.11 to 0.90 gm) and 4% mortality over a 28-week period.

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

A COMPARISON OF MORPHOMETRIC, BIOCHEMICAL AND PHYSIOLOGICAL INDICES OF CONDITION IN BIVALVE MOLLUSCS

Roger L. Mann

The present paper compares and evaluates a number of morphometric, biochemical and physiological parameters for their potential use as indices of condition in marine bivalve molluscs. Condition is defined as "the ability of an animal to withstand an adverse environmental stress, be this physical, chemical or biological". Using laboratory and field data, by the author and from literature, a comparison is made of the effect of one environmental stressor, temperature, on gravimetric and volumetric meat: shell condition indices, percentage organic content, carbohydrate, carbon and nitrogen, C:N and carbohydrate; protein ratios, weight specific ammonia excretion rate and oxygen consumption: ammonia excretion ratios in a number of commercially valuable species of oyster, clam and mussel.

Presented at: Savannah River Ecology Lab. Symposium on "Energy and Environmental Stress in Aquatic Systems", Augusta, Georgia, Nov. 1977.

Supported by: NOAA Sea Grant 04-6-158-44106 and Jessie Smith Noyes Foundation.

THE IMPACT OF CRUSTACEAN HERBIVORES ON CULTURED SEAWEED POPULATIONS

Mary E. Nicotri

The impact of two herbivorous crustaceans on seaweeds raised in an aquaculture system has

been estimated from laboratory determined grazing rates and estimated crustacean densities in the system. Grazing losses are generally very small in comparison to algal productivity but may be significant when crustacean populations are abundant and algal productivity is low.

Supported by: Noyes Foundation; NOAA Sea Grant Contract 04-6-158-44016 and U.S. ERDA Contract E(11-1) 2948.

*CULTIVATION OF SEAWEEDS FOR HYDROCOLLOIDS,
WASTE TREATMENT, AND BIOMASS
FOR ENERGY CONVERSION*

John H. Ryther, James A. DeBoer,
and Brian E. Lapointe

Development is described of seaweed culture systems in Woods Hole, Massachusetts, and Ft. Pierce, Florida for nutrient removal from domestic and animal culture wastewater, for commercial value for their hydrocolloids, and for a biomass source for conversion to methane or other fuels. Of various species evaluated, the red alga *Gracilaria foliifera* appears the best suited for all three purposes because of its ability to be grown vegetatively and essentially trouble-free over long periods of time and because of its high dry-weight yields of 26 metric tons/hectare over a 165-day growing season in Woods Hole and 112 metric tons/hectare on a year-round basis in Florida.

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*CULTIVATION OF SEAWEEDS
AS A BIOMASS SOURCE FOR ENERGY*

John H. Ryther, Brian E. Lapointe,
Richard W. Stenberg and LaVergne D. Williams

The history and present status of seaweed culture in the world in general and in the United States in particular are reviewed. Current research is summarized on the culture of the red alga, *Gracilaria foliifera* in Florida, including experiments on the effects of seaweed density, nutrient concentration, and water flow rate through the culture on yield. Annual yields of 112 tons dry weight per hectare per year obtained in small, intensive culture systems, are favorably compared with the highest sustained yields of agricultural crops reported in the literature.

Supported by: U.S. ERDA Contract E(11-1) 2948 and Grant from Florida Power and Light Company.

*WHAT DO YOU WANT TO DO WITH YOUR LAST
27,000 GALLONS OF OIL?*

Robert W. Howarth and C.A.S. Hall

Domestic petroleum resources in the United States are being rapidly depleted and cannot be depended on to support our energy needs for much longer. The economic ramifications of this are already being felt. Continued growth in energy consumption is neither desirable nor possible. The soft energy paths urged by Lovins represent our best energy future.

Supported by: W.H.O.I. Graduate Fellowship.

BENTHOS

*GEOGRAPHIC VARIATION IN RELATION TO
LIFE HISTORY OF THREE SPECIES OF THE MARINE
GASTROPOD GENUS Crepidula: GROWTH RATES OF
NEWLY HATCHED LARVAE AND JUVENILES*

Alison Stone Ament

Growth rates of newly hatched individuals of three species in the marine gastropod genus *Crepidula* from Cape Cod Bay and Delaware Bay were determined at a single temperature (18.5 C) within the normal physiological range. Values of Minot's relative growth rate, k , were computed for several successive age intervals. In *C. convexa*, a species without a larval dispersal stage, offspring from the northern population grew significantly more rapidly over the first 16 days than offspring from the southern population ($k = .030$ and $.020$, $p < .05$). In *C. fornicata*, a species with a planktotrophic larval stage of several weeks, offspring from the northern population also grew faster, the greatest contribution to populational difference occurring over the interval of day 2-6 ($k = .053$ and $.017$, $p < .01$). However, in the other species with a planktotrophic larval stage, *C. plana*, growth curves for northern and southern populations were remarkably similar (for day 2-6, $k = .046$ and $.040$, $p = .8$).

The intraspecific differences in growth rate appear to have a largely genetic basis. The more rapid growth rate in northern populations for two of the species suggests adaptive temperature compensation. The results with *Crepidula* and information in the literature on other species suggest that while species lacking a larval stage in their life history tend to be geographically genetically differentiated, species with a moderately long planktonic larval stage may or may not be genetically differentiated between populations. Possible causes for differences in the pattern of geographic variation between *C. plana* and *C. fornicata*, despite similarity in life history, are discussed.

Information is given on length of brooding period, duration of the larval stage and settlement size. Settlement size in the species with larvae is very similar to hatch size in the species with direct development.

In press: *Belle W. Baruch Library in Marine Science*, Vol. 9 "Reproductive Ecology of Marine Invertebrates".

Supported by: NSF Grant DES 75-06343.

*ZONATION IN THE DEEP BENTHIC MEGAFUNA:
APPLICATION OF A GENERAL TEST*

Frederick P. Gardiner and Richard L. Haedrich

A test based on Maxwell-Boltzman statistics, instead of the formerly suggested but inappropriate Bose-Einstein statistics (Pielou and Routledge, 1976), examines the distribution of the boundaries of species' ranges distributed along a gradient, and indicates whether they are random or clustered (zoned). The test is more useful as a preliminary to the application of more instructive but less statistically rigorous methods such as cluster analysis. The test indicates zonation is marked in the deep benthic megafauna living between 200 and 3000 m, but below 3000 m little zonation may be found.

Supported by: NSF Grant DES 74-22339.

*LIFE HISTORIES AND GENETIC VARIATION
IN MARINE INVERTEBRATES*

J. Frederick Grassle and Judith P. Grassle

The proportion of polymorphic loci in six sibling species of *Capitella* (Polychaeta) is related to a combination of population response time following disturbance and dispersal ability measured as length of larval life. The literature on protein polymorphisms in marine invertebrates is reviewed in the context of three generalizations: 1. Species with better individual regulatory ability (including physiological tolerances, mobility and behavioural adaptations) have lower genetic variability. 2. Species in environments where temporal change is less variable and severe have greater genetic variability. 3. Species with greater dispersal ability tend to be less divided into subpopulations and have lower genetic variability. The high genetic variability of species in tropical and deep-sea environments is best explained in terms of biotic spatial heterogeneity. Further studies of genetic variation should be accompanied by analyses of life histories and population structure.

In press: *Marine Organisms: Genetics, Ecology and Evolution*, Plenum Press, New York.

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*FAUNAL CHANGES WITH DEPTH
IN THE DEEP-SEA BENTHOS*

J. Frederick Grassle, Howard L. Sanders,
and Woolcott K. Smith

A single method, the normalized expected species shared measure of similarity or NESS, is used to measure faunal change with depth for gastropods, cumaceans, polychaetes and ophiuroids. Each group has a characteristic pattern of zonation on the Gay Head-Bermuda transect, with the greatest changes in faunal composition occurring on the outer margins of the continental shelf and between upper slope and middle slope depths. Changes in cumacean species with both depth and distance between ocean basins are compared for Eastern and Western basins of the North Atlantic.

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MEGAFUNAL BIOMASS IN THE DEEP OCEAN

Richard L. Haedrich and Gilbert T. Rowe

Abundance and biomass of the megafauna (large epifaunal invertebrates and demersal fishes) on the continental slope and rise off southern New England were determined from a combination of trawling and extensive bottom photography. Megafaunal biomass is of the same order of magnitude as macrofaunal biomass, and thus the megafauna must depend to a considerable degree on falls of large dead animals from the pelagial for food. For fishes, there is a positive correlation between size and depth, as would be expected for animals which must search large barren areas for a few discrete items.

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*MODELSEA: TOWARDS A SIMULATION OF PARTICULATE
ORGANIC CARBON FLOW IN THE OPEN OCEAN*

John F. Muratore and Richard L. Haedrich

Biological oceanographers have long been interested in the flow of materials through marine ecosystems. The release of toxic substances into the oceans has made this a topic of great applied importance. MODELSEA is an attempt to use a deterministic specific process numerical simulation model to consider the process of particulate organic carbon (POC) flow in the open

ocean. MODELSEA considers the flow of POC in a 2000 m deep column of water under a hectare of open ocean. In the model, detritus is generated at various depth levels as a function of the standing crops of various organisms, is eaten by organisms, decays and sinks. Detritus is generated for a single day and is then tracked until it either hits bottom or is consumed. The sum of material reaching the bottom over the simulation equals the daily input to the bottom. Thus, it is possible to predict the flow of POC to the bottom without making assumptions about the distribution of detritus in the water column. The food web used in the model is nontrivial and is intended to represent a generalized open ocean food web.

When the model is run with best estimates from the literature for all parameters, it predicts a flow of 1.45 g material/(m²/day). The dominant component is zooplankton fecal pellets 1.40 g/(m²/day). This compares to measured rates in the literature of between 74 and 242 mg material/m²/day). The differences between model predictions and observations may be due to both sampling problems and underestimates of feeding on fecal pellets in the model. Model predictions also suggest that approximately one gram of dead fish carcass should be reaching each 25 m² of bottom per day. This suggests two possible life styles for deep benthic organisms. The first is keyed to small and more abundant fecal pellets, and the second is keyed to larger carcasses.

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PATTERNS OF SPECIES DIVERSITY: FACT OR ARTIFACT?

Richard Osman and Robert Whitlatch

The pattern observed in nature has often served as a compelling motivation for seeking the underlying processes which are assumed to control the pattern. Spatial and temporal patterns of species diversity are the most commonly observed and described from the study of recent and paleo-communities. These patterns include those found within a local or discrete region such as succession and changes along an environmental gradient and inter-regional or global patterns such as latitudinal diversity gradients and comparisons of the deep-sea and the continental shelf faunas. Many hypotheses have been advanced to explain these patterns in terms of differences in the biology of species adapted to different or changing environments. However, a more simple explanation is possible; that these patterns do not result from any specific biologic processes.

We examine this possibility and show that succession can result from probabilistic immi-

gration and local extinction of species, diversity gradients can result from probabilistic disturbance in naturally patchy environments, and that latitudinal gradients are simply a function of the shape of the earth. As long as such diversity patterns can be explained independent of any specific biologic processes, they offer no test of the importance of these processes, either ecologically or evolutionarily.

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PHYSIOLOGICAL ECOLOGY OF ENCAPSULATED DEVELOPMENTS IN MARINE INVERTEBRATES

Jan Pechenik

The gastropod *Nassarius obsoletus* deposits its egg capsules in the intertidal zone. Contrary to expectation, the capsules are poorly adapted for protecting the enclosed embryos against desiccation stress. Protection of the embryos depends instead upon the behavior of the depositing female; capsules are preferentially deposited into high humidity environments where the embryos will be spared exposure to desiccation stress at low tide. The survival advantages of encapsulation are made particularly puzzling by the fact that encapsulation is followed by a relatively long period of planktonic development in many species, including *N. obsoletus*. By means of a simple probability argument, it is suggested that even a short period of encapsulation can significantly reduce mortality during development if mortality rates in the plankton are sufficiently low. The survival advantages of limited periods of encapsulation are increased if free-swimming larvae are more likely to survive than are free-living earlier developmental stages. It is suggested that egg capsules may function to retain the embryos until the embryos are capable of actively staying up in the water column, thereby avoiding benthic mortality sources.

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Fellowship.

SOURCES OF ORGANIC MATTER TO THE DEEP-SEA BENTHOS

Gilbert T. Rowe and Nick Staresinic

Particulate organic matter (POM) in the deep sea is derived from five major sources: planktonic material, carcasses of large nekton, marine macrophyte detritus, terrigenous matter and chemotrophic production.

The direct contribution of terrigenous matter to deep marine sediments is small. Sediment trap measurements show that small planktonic POM adds about 4 g C m⁻² yr⁻¹ to the deep-sea carbon

pool. The maximum expected input of pelagic *Sargassum* to the deep Atlantic is one-tenth of this, $0.4 \text{ g C m}^{-2} \text{ yr}^{-1}$. Calculations suggest the remains of large nekton contribute approximately $50 \text{ mg C m}^{-2} \text{ yr}^{-1}$ while the rate of primary carbon synthesis by chemoautotrophs is estimated to be $0.1 \text{ mg C m}^{-2} \text{ yr}^{-1}$.

In press: *Ambio*.

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SEDIMENTATION RATES IN THE SLOPE WATER OF THE NORTHWEST ATLANTIC OCEAN MEASURED DIRECTLY WITH SEDIMENT TRAPS

Gilbert T. Rowe and Wilford D. Gardner

Four sediment trap arrays were deployed in the Slope Water off the northeast United States for periods of 5.8 to 15.8 days from May to August 1976. Three traps, each a PVC cylinder 25 cm in diameter and 76 cm long, were attached at various distances above the bottom along bottom-anchored moorings. Closure of the individual traps and release of each array from its expendable anchor was controlled by a Williams Timed Release or an AMF acoustic release. D.S.R.V. *Alvin*, making observations of one array, closed those traps and released that array from the bottom.

Water depths ranged from 2200 m to 3650 m, but the traps were put as high as 518 m off bottom, as well as near bottom, to differentiate between primary pelagic sedimenting matter and resuspended material in the nepheloid zone.

Average organic carbon sedimentation rate for all traps was $12.8 \text{ mg/m}^2/\text{day}$, while CaCO_3 averaged $105 \text{ mg/m}^2/\text{day}$. Organic carbon ranged from 3.8 to 6% of the total material caught, somewhat higher than that in bottom sediments (1.2 - 1.3%) below the traps. Size fractionation of some of the material indicated that about 20% of the organic carbon flux was carried in larger, often pelletized particles ($> 63 \mu\text{m}$), with the remaining 80% being in smaller particles. Fecal pellets were larger and more abundant near bottom in the nepheloid zone than in the primary sedimenting material above it, suggesting that the fauna on and near (500 m above) bottom recycles resuspended and primary matter before it is deposited.

Carbon budgets for the three locations, based on community metabolism, the trap measurements and carbon accumulation in the bottom, suggest that the inferred assemblage of organisms just above bottom could be utilizing a relatively large unaccounted for fraction of the primary sedimenting organic carbon.

Extrapolation of these measurements to an annual, open-ocean carbon budget indicates

that as much as $3 \times 10^{15} \text{ g}$ carbon could enter the deep sea annually as particulate matter. If this be true, it is one way the deep-sea could be acting as a significant sink for carbon on a global scale.

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PHOTOGRAPHIC STUDIES OF THE BENTHIC ABUNDANCE AND SMALL-SCALE DISPERSION PATTERNS OF THE RED CRAB Pleuroncodes planipes (DECAPODA, GALATHEIDAE) OFF BAJA CALIFORNIA, MEXICO

Gilbert T. Rowe and C. Hovey Clifford

A photographic survey of a small region of the seafloor off Baja California has been used to quantify the abundance and biomass of red crabs on the bottom. Maximum abundances were found very close to shore (average of 245 crabs m^{-2}). Estimated biomass was 1370 gms wet weight m^{-2} . The crabs were either well-dispersed over the bottom or in tightly compacted clumps measuring 0.5-1 m in diameter. Benthic abundances were much less offshore. During periods of high winds and rough seas the crabs remained on bottom at night, rather than migrating up into the water column.

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FLORIDA OIL SPILL IMPACT ON THE BUZZARDS BAY BENTHIC FAUNA: WEST FALMOUTH

Howard L. Sanders

The densities and species composition and the array of statistical methodologies demonstrate that the same hierarchical pattern emerges no matter what criterion is used to measure the effects of the oil spill. Densities and species composition remain stable over time at the minimally oiled and unoled stations but display considerable density fluctuations and marked changes in species composition at the more heavily oiled stations. Using simple presence or absence data, highest fidelity is present at the marginally oiled stations, lower fidelity at the intermediately oiled stations and lowest fidelity at the severely oiled stations. The Discrepancy Index measures mean yearly differences in faunal composition at each of the stations. Very large and large differences are documented for the severely and intermediately oiled stations but only small differences are found for the marginally oiled stations. The Coefficient of Variation is a measure of faunal variability throughout the entire sampling period for each of the stations. Faunal variation remains very high at the severely and intermediately oiled stations but low at the

marginally oiled sites. Diversity (not considered in the body of this paper), when corrected for obvious artifacts imposed by very low density samples, gross dominance and the differential contributions made by equitability and species richness to the various diversity indices, is highest at the marginally oiled stations, lower at the intermediately oiled stations and lowest at the severely oiled stations. Increased diversity values over time found at stations recovering from the oil spill are primarily a response to species richness rather than greater equitability. Cluster analysis reveals profound temporal changes in the fauna from samples collected at the severely and intermediately oiled stations but demonstrates a much more homogeneous pattern with only small seasonal changes from samples obtained at the marginally oiled stations.

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EVOLUTIONARY ECOLOGY AND
LIFE HISTORY PATTERNS IN THE DEEP SEA

Howard L. Sanders

It has been proposed that the high diversity found in the deep sea is the product of the stability of the physical environment for long periods of time. The low level of environmental uncertainty allows the extensive biological interactions occurring over evolutionary time in these minimal varying physical environments to be in the direction of reduction in biologic stress. The historic results are stable and complex Biologically Accommodated Communities composed of large numbers of stenotopic species. Although diversity is high in the deep sea, not all major taxa contain a diverse array of species. Species belonging to low diversity taxa tend, on the average, to have broader depth ranges, are more cosmopolitan and eurytopic, produce larger number of eggs and have a larval stage that allows wide dispersion. These are life history features that typically characterize the biota of more physically stressed, low diversity habitats such as shallow boreal seas dominated by a Continental Climate and estuaries. Similar contrasting life history patterns can be demonstrated when the fauna from historically stable environments are compared to their counterparts from more variable habitats independent of whether the comparison is made within a marine, freshwater or terrestrial regime. The interrelated life history features that are selected for along the two diverging

evolutionary pathways lead toward low diversity, physically controlled or high diversity, biologically accommodated communities and r or K modes of existence.

Alternate interpretations, based on the premise that there is an increased proportion of predators relative to their prey, have been suggested for the high diversity present in the deep sea. Through intensive cropping, the deep-sea benthos is kept biologically undersaturated and, thus, permitting more species to be present by reducing competition for resources. Yet, whenever mortality rates are high, the species must be r or physically controlled rather than K or biologically accommodated strategists. What we know of life history characteristics of the fauna at great depths suggest that the thesis of intensive predation as the source of high diversity in the deep sea may not be correct.

In situ experiments on the deep-ocean floor reveal that life processes and rates are much slower than in shallow water. However, if a species is dependent on an event of low predictability in this near chemostatic environment for survival, it evolves a markedly opportunistic life history with elevated rate processes that typify more physically controlled environments.

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STUDIES ON THE DEEP SEA PROTOBRANCHIA
(Bivalvia); THE FAMILY TINDARIIDAE AND
THE GENUS *Pseudotindaria*

Howard L. Sanders and John A. Allen

In the present paper we have erected a new family of Protobranchia, the Tindariidae, to include those nuculanoid bivalves that lack a siphon but bear papillae on their posterior margin edge, have a single loop of the hind gut that penetrates the right side of the mantle, and possess a palp with few ridges. A new genus, *Pseudotindaria*, is created for those nuculanoid protobranch bivalves that have shell morphologies essentially similar to the Tindariidae but with soft parts that are markedly different. Siphons are present, the hind gut is a complex configuration of loops and coils on either side of the body and it does not penetrate the mantle, and palp ridges are numerous. The morphologies of the hard and soft part anatomies, the horizontal and vertical distributions, size-frequency histograms, and reproductive patterns of the tindariid and pseudotindariid species in our Atlantic samples are discussed. Two new species are described. On the basis of shell morphology, *Tindaria* and *Pseudotindaria* can be interpreted as recent descendants of the Paleozoic ctenodont Protobranchia.

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THE LACTATE DEHYDROGENASE-A POLYMORPHISM OF Anoplarchus purpureus IN CENTRAL CALIFORNIA

Clay A. Sassaman and Ronald M. Yoshiyama

Studies by Johnson (1971, 1977) on the LDH-A polymorphism of the stichaeid fish *Anoplarchus purpureus* in Puget Sound have identified two environmental factors, oxygen concentration and temperature, which are highly correlated with gene frequencies at this bi-allelic locus. We have surveyed populations in California to determine whether or not gene frequencies near the southern end of the species' distribution are consistent with expectations based on the previously observed environmental correlations. Populations in northern California are in general agreement with an hypothesis of a direct temperature influence on gene frequency; however, populations south of Monterey Bay are not. Several lines of circumstantial evidence suggest that the discrepancy in southern populations is not the result of isolation and drift, or of genetic background. Several hypotheses are suggested to explain both the Washington and California data. Explanations based on either oxygen concentration or thermal variation are consistent with our own and previously published field data, but in light of laboratory experiments conducted by Johnson (1971), the hypothesis invoking a direct influence of oxygen concentration on allele frequency is viewed as the weaker of the two explanations.

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ON THE RELATIONSHIP BETWEEN DISPERSAL OF PELAGIC VELIGER LARVAE AND THE EVOLUTION OF MARINE PROSOBRANCH GASTROPODS

Rudolf S. Scheltema

The concept of evolution as it is now generally understood includes two different phenomena; these are (1) the gradual transformation of species in time, and (2) the multiplication of species by reproductive isolation (i.e., allopatric speciation). An hypothesis is proposed that relates both of these phenomena to the effective-larval-dispersal capability of benthic marine species.

It is predicted that prosobranch gastropods with teleplanic or "long distance" larvae will be broadly adapted species with large genotypic variability, broad geographic range and great temporal longevity. Species with a pelagic development of more restricted duration (e.g., three to six weeks) and hence

with less dispersal capability will show geographic variation in genotype and varying degrees of speciation (or species radiation). Disjunct vertical and geographical distribution will occur among such forms. Species completely lacking a pelagic dispersal stage will more nearly fit the classical concept of "gradualism"; they will have restricted geographic range and must either change with their environment (i.e., show "phyletic evolution") or become extinct. Such species can be expected to persist for only short intervals of geologic time.

Inferences from contemporary species and the fossil record are presented to support the hypothesis presented.

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MEASUREMENT OF THE VERTICAL FLUX OF PARTICULATE ORGANIC MATTER WITH A FREE-DRIFTING SEDIMENT TRAP

Nicholas Staresinic, Gilbert T. Rowe, Albert J. Williams III and Daniel Shaughnessey

Measurements of the vertical flux of particulate organic matter have previously been made with moored sediment traps. *In situ* dye experiments conducted in Buzzards Bay, Massachusetts, suggest that, in a current as low as 15 cm/sec, the turbulent wake established over the entrance of such a device may severely bias estimation of both the quantity and quality of material settling through the water column. Similar experiments indicate that a free-drifting trap is not hampered by this problem and may thus be a superior sampler. The free-drifting mode also permits 1) shallow deployments in deep water columns without the engineering problems accompanying deep moorings, and 2) tracking of particular water parcels, such as upwelling plumes.

In press: *Limnology and Oceanography*.

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EL FLUJO VERTICAL DE MATERIA ORGÁNICA PARTICULAR EN EL AFLORAMIENTO DEL PERU

Nicholas Staresinic

Durante el Abril y el Mayo, 1977, se midieron el flujo vertical de la materia orgánica particular en el afloramiento costero peruano con una trampa flotada de sedimentos (inglés: Floating Sediment Trap). Hace seis horas se situaron las trampas en la base de la

zona eufotica (casi 50 metros). Ellas colectaron un organico $m^{-2} dia^{-1}$. En una base anual, estos valores son semejantes a esos de los estuarios de pocos profundos. Comparado con la producción primaria, cada día seis a veintitres porcentaje del carbono organico producido del fitoplancton se hundió a través de la zona eufotica. Se varían mucho la calidad de la materia organica hundida entre las estaciones ocupadas. Cuando el porcentaje de la producción primaria hundiendo de la zona eufotica fue alto, se dominaron las heces del zooplancton ("fecal pellets") y de las anchovetas ("fecal casts"); cuando este porcentaje fue bajo, se dominaron la materia colectada las distomeas (por ejemplo, cadenas de *Chaetoceros affinis* y individuos de *Coccolithus* sp.).

Se hundieron los fragmentos de las heces de la anchoveta con la tasa dos centímetros por segunda. Esta tasa, aproximadamente dos veces más que las tasas medida por crustáceos zooplanctónicos, sugiere que la anchoveta es muy importante en el transporte de materia planctonica a la exosistema bentónica.

En un estudio acerca de Huarney, se observa una variación diurna en la composición de la materia organica particular hundiéndose. La piel fresca de eufausáceos (después de mudar) se obtuvieron solo en la noche. Ahora se desconoce la importancia cuantitativa de las poblaciones que migran verticalmente en el transporte rápido de materia producida en las aguas superficiales a las profundidades.

Supported by: *Tai-Ping Foundation*.

ON THE ESTIMATION OF SECONDARY PRODUCTION

Nicholas Staresinic

Methods commonly used in the calculation of secondary production are closely related. A graphical derivation of the relationship between the production increment method and the mortality increment method is given. The method of summation of successive mortality increments yields a true estimate of production only when time-changes in biomass are considered.

Supported by: *WHOI Predoctoral Fellowship*.

PELAGIC LARVAE OF NEW ENGLAND GASTROPODS.
V. *Bittium alternatum*, *Trophora nigrocincta*;
Cerithiopsis greeni, *Cerithiopsis emersoni*;
Lunatia heros and *Crepidula plana*.

Catherine Thiriot-Quievreux
and Rudolf S. Scheltema

The veliger larvae of six New England prosobranch gastropod species are described for the first time. Characteristics of the living larvae are given and scanning-electron microscope micro-

graphs show details of the larval shells. The species for which veligers are described include *Bittium alternatum*, *Trophora nigrocincta*, *Cerithiopsis greeni*, *Cerithiopsis emersoni*, *Lunatia heros*, and *Crepidula plana*. This study brings to 15 the number of gastropod veligers from the Woods Hole region known from published descriptions and illustrations.

In press: *Malacologia*.

Supported by: *NSF Grant OCE 73-00439 A02*.

BIOACOUSTICS

AERIAL OBSERVATION OF FEEDING BEHAVIOR IN FOUR BALEEN WHALES: Eubalaena glacialis, Balaenoptera borealis, Megaptera novaeangliae, AND Balaenoptera physalus.

William A. Watkins and William E. Schevill

Distinct behavioral differences were noted from aerial observations of four species of baleen whales feeding together in the same water on 30 April and 1 May, 1975: *Eubalaena glacialis* (right whale), *Balaenoptera borealis* (sei whale), *Megaptera novaeangliae* (humpback whale), and *Balaenoptera physalus* (finback whale). The right and sei whales fed together on patches of plankton; right whales fed steadily with mouths open in the densest areas, while the sei followed a more erratic path through the patches, alternately opening and slowly closing its mouth with slight throat distension at each closing. Humpback and finback whales fed together on dense schools of fish associated with the patches of plankton, the humpback fed in discrete rushes generally from below the schools of fish, while finback feeding was by more horizontal passes sometimes characterized by sharp turns and rolls within the fish schools, often with enormous throat distension.

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ONR #N00014-74-C-0262; NR 083-004.

SPERM WHALE ACOUSTIC BEHAVIOR

William A. Watkins

The story of our progress in the study of sperm whale acoustic behavior shows that sound plays an important role in their lives. Their click sounds apparently are used to maintain contact with other whales underwater and perhaps to communicate individual identity. By tracking their sounds with arrays of hydrophones various behaviors were observed, including wide-spread underwater distributions, 10-15° dive angles, 2 to 4-kt underwater swimming speeds, and long dive times.

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SPERM WHALE CODAS

William A. Watkins and William E. Schevill

Short series of 3 to 40 or more clicks are produced by sperm whales, *Physeter catodon*, in stereotyped repetitive sequences or codas. The click patterns in codas appear to be unique to particular whales in an area over at least a few hours. It is suggested that sperm whale codas serve as a means of individual acoustic identification. An exchange of codas between two animals was analyzed and acoustical locations calculated from the 4-hydrophone array data indicated that changes in underwater movement coincided with changes in the coda sequences.

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THE DEVELOPMENT AND TESTING
OF A RADIO WHALE TAG

William A. Watkins and William E. Schevill

A 200 mwatt, 27 MHz radio whale tag has been developed for tracking whales at sea. It is remotely implanted and will transmit continuously for about 90 hours, equivalent to 16 weeks on a normally behaving finback. The tag has developed from initial efforts to tag right whales with radios in 1961-1965. The tag and its launching system were tested on whale carcasses at the Icelandic whaling station. With 1977 modifications, the radio whale tag appears to be ready for field trials on orquals.

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

FISHES

FAMILY MYCTOPHIDAE

B.H. Nafpaktitis, R.H. Backus, J.E. Craddock,
R.L. Haedrich, B.H. Robison and C. Karnella

This is an account of the systematics and distribution of the 82 species of Myctophidae (lantern fishes) found in the North Atlantic. The distribution map for each species is based on material from 1022 midwater trawls made at the Woods Hole Oceanographic Institution between 1961 and 1974.

Supported by: NSF Grants DES 74-23209 and GA-31365 XI.

ATLANTIC MESOPELAGIC ZOOGEOGRAPHY

Richard H. Backus, James E. Craddock,
Richard L. Haedrich and B.H. Robison

A zoogeographic system for the Atlantic Ocean between the southern borders of the Arctic and the subtropical convergence at 35°S is explained. The area considered is divided into 20 faunal provinces; these are grouped into faunal regions - Atlantic Subarctic, North Atlantic Temperate, North Atlantic Subtropical, Atlantic Tropical, South Atlantic Subtropical, Gulf of Mexico, and Mauritanian Upwelling. The division is based on the nine patterns according to which myctophid fishes are distributed in the area considered. The system is based on the study of a quarter-million specimens of myctophids found in 1022 midwater trawls made at the Woods Hole Oceanographic Institution between 1961 and 1974.

Supported by: NSF Grant DES 74-23209.

RECENT CHANGES IN THE POPULATION OF JUVENILE
ATLANTIC SALMON IN THE MATAMEK RIVER,
QUEBEC, CANADA

R. John Gibson

Investigations have been conducted on Atlantic salmon in the Matamek River since 1967. Numbers of juveniles have decreased in recent years and their growth has increased. Two-year-old smolt were not found in 1967 but in 1976 made up 20% of the run. The majority continued to migrate at three years old. The ratio of male to female smolt in 1967 was about one-to-one, but in 1976 was about one-to-three. The proportion of precocious male parr appears to have increased. The habitat has remained unchanged, and the fish are unexploited except for controlled scientific sampling. The changes are probably due to a reduced egg deposition. The ratio of two-sea-year salmon: grilse has decreased from 1:1.1 to 1:4.5 and the number of two-sea-year salmon appears to have decreased.

In press: *Journal du Conseil*.

Supported by: WHOI Matamek Research Program.

THE BEHAVIOR OF JUVENILE ATLANTIC SALMON
(*Salmo salar*) AND BROOK TROUT (*Salvelinus fontinalis*) WITH REGARD TO TEMPERATURE
AND TO WATER VELOCITY.

R. John Gibson

Salmon parr and brook trout were observed in stream tanks at the Matamek Research Station, Quebec. In the autumn, at 10°C salmon parr began sheltering in rubble, and at 9°C the majority had disappeared into hiding. Trout also

had this tendency to hide at cold temperatures, but not as strongly as the salmon. In slow water flows also (<5 cm/sec) salmon parr tended to hide in the rubble substrate, and aggression decreased. In both slow and faster water velocities the commonest agonistic act by salmon parr was "charge and chase". Trout in July showed "nip" as the commonest agonistic act, but in September and October "approach" and "charge and chase" were more common, possibly due to aggression associated with spawning. Shade was attractive to both species in shallow water, but given the choice of a shallow (30 cm) tank with a shade cover, and a deeper (50 cm) tank with no shade, the majority of trout and salmon selected the deeper tank. In one experiment in a shallow water tank, turbulent water surface was more attractive to salmon parr than shade.

Supported by: *Atlantic Foundation.*

*AN OCCURRENCE OF Fundulus diaphanus (Leseuer)
ON THE NORTH SHORE OF THE GULF OF SAINT*

R. John Gibson and Richard Sears

Fundulus diaphanus was found in a shallow lake on the coast close to the Matamek River (50°18'N and 65°57'W) during August 1976. This is the first time the species has been reported from the North Shore of the Gulf of St. Lawrence and makes a slight northern extension of its known range.

Supported by: *Atlantic Foundation*

ESTUARINE FISHES

Richard L. Haedrich

The chapter examines the nature of estuarine fish faunas, their variation in time and space, the life histories of estuarine fishes, and the influence on estuarine fishes of man's activities. Several hundred literature citations are provided. A few main points emerge from the general review:

1. Fish production is high in estuaries, but diversity tends to be low. Diversity increases slightly in the tropics, but not markedly so.

2. Estuarine fish fauna are derived from marine groups, and there are rather few truly estuarine fishes.

3. Estuarine faunas are very similar in composition around the world. Salmonids dominate in cold water, and gobies, mugilids, sciaenids, sparids, and flatfish dominate in warm and temperate regions.

4. Estuaries are important nursery areas for young fish spawned in either fresh water or at sea, but little spawning takes place in estuaries.

5. Still needed is work on natural history, distribution, and true production. Even standing stock estimates are scarce, and the problem of distinguishing "estuarine" from "inshore" remains.

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

*DISTRIBUTION OF BOTTOM FISHES IN THE
DENMARK STRAIT AND IRMINGER SEA*

Richard L. Haedrich and Gerhard Krefft

Analyses of 27 bottom trawl collections from the Denmark Strait and Irminger Sea show that five faunal assemblages of fishes can be identified. These are separable on the basis of faunal composition, diversity, evenness, catch rate, and the combination of depth and temperature at which each occurred. One group is found at 2026-2058 m depth and temperatures of 1.3-3.4°C, a second at 763-1503 m and 3.9-5.6°C, a third at 280-776 m and 1.4-7.4°C, a fourth at 493-1519 m and 0.1-3.0°C, and a fifth at 330-693 m and (-)0.7-(+)0.5°C. The assemblages are like those described for fishes trawled on the Iceland-Faeroe Ridge during an earlier expedition in 1960, although the relative dominance by commercial species has declined. Cold-water assemblages and species are found along the path of the Norwegian Sea water that flows south on the bottom through the Denmark Strait and down across the continental slope to the west. The percentage of primary deep-water species in each assemblage increases evenly with depth, suggesting a gradual and continuing invasion of the deep sea in this region by phylogenetically younger secondary deep-water forms. The smooth transition from an essentially shallow-water fauna to an essentially deep-water one as seen in the demersal fishes contrasts with the more abrupt transition found in pelagic fishes. The meso- and bathypelagic forms, presumably higher specialized and finely tuned to their environment, are more successful in resisting invasion and colonization from newer groups. In the demersal assemblages, there is good correlation between the number of species present and the heterogeneity of the local environment as reflected in the temperature range over which each of the assemblages occurs.

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

BRAMIDAE

Richard L. Haedrich

A brief diagnosis, descriptions, and keys to genera are provided for the oceanic fish family Bramidae.

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

Adrianus J. Kalmijn

- The discovery of an unconventional sensory modality.
- Field observations on Cape Cod sharks.
- Experimental evidence of geomagnetic orientation.

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

*LIFE HISTORY AND FISHERIES OF
ATLANTIC BLUEFIN TUNA*

Frank J. Mather, III, John M. Mason, Jr.,
Howard A. Schuck and Albert C. Jones

The History of the Fisheries of the Atlantic Bluefin Tuna is discussed.

Supported by: *A lifetime of work.*

MICROBIOLOGY

*CONTROLLED ECOSYSTEM POLLUTION EXPERIMENT:
EFFECT OF MERCURY ON ENCLOSED WATER COLUMNS -
MARINE BACTERIOPLANKTON*

Fariq Azam, Ralph F. Vaccaro, Paul A.
Gillespie, E.I. Moussalli and R.E. Hodson

Some effects of low concentrations (1 and 5 $\mu\text{g l}^{-1}$) of added Hg^{2+} on natural marine bacterioplankton were examined in Controlled Experimental Ecosystems, plastic cylinders containing 1300 m^3 of seawater and its complement of natural biota from Saanich Inlet, British Columbia. Heterotrophic activity, measured as D-glucose assimilation and respiration, was initially inhibited by 1 $\mu\text{g l}^{-1}$ Hg to less than 1% of the control, followed by a rapid (5 days) recovery to the "normal" level. Bacterial biomass, estimated from adenosine-5'-triphosphate in bacterial size fraction, decreased to 8-40% of the control, but also recovered within 5-7 days. The succeeding bacterial populations showed enhanced Hg-tolerance, and were also copper tolerant although no Cu additions were made to the enclosures. It is suggested that, whereas decrease in bacterial standing stocks and heterotrophic activity is only transient, the dominance of Hg (and Cu) tolerant bacteria in mercury-polluted ecosystems may have implications for the biologically-mediated fate of mercury.

Supported by: *NSF Grant OCE 73-05941 A02.*

*A BACTERIAL BIOASSAY FOR MEASURING THE
COPPER-CHELATION CAPACITY OF SEAWATER*

Paul A. Gillespie and Ralph F. Vaccaro

A relatively simple ^{14}C tracer bioassay technique which uses a copper sensitive bacterium isolated from Saanich Inlet, British Columbia to measure the copper chelation capacity of seawater is described. Known increments of ethylenediaminetetracetic acid are used to evaluate decreased bacterial inhibition accompanying reduced cupric ion activity. Ultraviolet irradiation and selective filtration of natural seawaters indicate that organic assemblages having molecular weights below 10,000 are principally responsible for copper chelation. Copper chelation capacities for oligotrophic as opposed to eutrophic marine waters ranged from 3 to 40 $\mu\text{g liter}^{-1}$ copper. Some implications of these data affecting metal toxicity in the sea are described.

Supported by: *NSF Grant IDO 73-05941.*

*A SEMIAUTOMATED PERSULFATE OXIDATION TECHNIQUE
FOR SIMULTANEOUS TOTAL NITROGEN AND TOTAL PHOSPHORUS
DETERMINATION IN NATURAL WATER SAMPLES*

Patricia M. Glibert and Christopher F. D'Elia

A semiautomated method for the determination of total nitrogen and total phosphorus in natural waters couples a manual alkaline persulfate digestion with Technicon AutoAnalyzer methodology. In the 0-25.00 $\mu\text{g atoms N liter}^{-1}$ range, nitrogen recovery was quantitative, with a standard error of 0.29 $\mu\text{g atoms N liter}^{-1}$ on duplicates. Phosphorus recovery was also quantitative, with a standard error on duplicates of 0.045 $\mu\text{g atoms P liter}^{-1}$.

Supported by: *ERDA Contract E(11-1)-2948, Jessie Smith Noyes Foundation, and OIP.*

*A RAPID AND PRECISE METHOD FOR DETERMINING
SULFATE IN SEAWATER, ESTUARINE WATERS
AND SEDIMENT PORE WATERS*

Robert W. Howarth

Sulfate can be rapidly and accurately measured by means of an indirect titration. Barium sulfate is precipitated in acid EDTA solution, the precipitate is filtered and dissolved in an excess of EDTA at high pH, and the excess EDTA is titrated with MgCl_2 . Interferences from chloride, iron, or phosphate are negligible. Sulfides may interfere, but a procedure to remove this interference is suggested. The method accurately determines the sulfate concentration in 1.0 ml of seawater with a standard deviation which is consistently less than 0.5% of the mean determination of the three replicates.

Supported by: NSF Grants OCE 74-17859 and
DEB 76-83877.

*MICROBIAL DECOMPOSITION OF ORGANIC MATTER
IN THE DEEP SEA*

Holger W. Jannasch

Measurements of growth and respiration of deep sea bacteria have been conducted under unchanged environmental conditions, i.e. pressure and temperature. In all cases, the metabolic activity in undecompressed water samples was lower than it was when incubated at 1 atmosphere. The processes involving substrate incorporation into cell material were more pressure sensitive than was respiration. No barophilic growth response (higher rates at elevated pressure than at 1 atmosphere) was found; all populations observed exhibited various degrees of barotolerance.

Supported by: NSF Grants DES 75-15017
and OCE 75-21278.

MICROORGANISMS AND THEIR AQUATIC HABITAT

Holger W. Jannasch

The physico-chemical properties of water are brought in perspective with the growth characteristic and biochemical requirements of aquatic microorganisms. The behavior of freely suspended and of attached bacterial populations, including the formation of anaerobic micro-habitats on suspended particulate matter, is discussed.

In press: *Environmental Biogeochemistry*.
Krumbein ed. Ann Arbor Sci. Publ.

Supported by: NSF Grants DES 75-15017
and OCE 75-21278.

METHANE CYCLING IN AQUATIC ENVIRONMENTS

John W. M. Rudd and Craig D. Taylor

A review article on the biological production and oxidation of methane gas. The interrelationships between these two processes in the cycling of methane carbon in the aquatic environment are discussed.

Supported by: NSF Grants DES 75-15017 and
OCE 76-21278 and WHOI Postdoctoral
Fellowship.

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

Craig D. Taylor

The presence of an oxy-helium atmosphere at a pressure of 500 atmospheres (atm) had no detectable effects on the growth of a marine

organism, EP-4, relative to hydrostatic pressure control cultures. Rapid decompression (2-3 minutes) resulted in outgassing of helium which markedly reduced the measured incorporation of radiolabelled substrate into trichloroacetic acid precipitable cell material. This effect was eliminated by extending the decompression time to 30 minutes. A hydrostatic pressure of 500 atm decreased both the growth rate and the rate of incorporation of substrate into cell material approximately three fold as compared to an approximately 1.4 fold reduction in the respiration rate. Dissolved oxygen in the hyperbaric system at levels 40% higher than that present in air equilibrated medium did not result in detectable detrimental effects.

Supported by: NSF Grant DES 75-15017.

*MICROBIAL DARK ASSIMILATION OF CO₂
IN THE CARIACO TRENCH*

Jon H. Tuttle and Holger W. Jannasch

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

In press: *Limnology and Oceanography*.

Supported by: NSF Grant DES 75-15017.

*THIOSULFATE STIMULATION OF MICROBIAL DARK
ASSIMILATION OF CARBON DIOXIDE
IN SHALLOW MARINE WATERS*

Jon H. Tuttle and Holger W. Jannasch

The effect of thiosulfate on dark assimilation of carbon dioxide in shallow, marine environments was investigated in order to explain the recent discovery of bacterial thiosulfate oxidation in aerobic, open ocean seawater. The results demonstrate that the potential exists for microbial thiosulfate oxidation to increase both dark assimilation of carbon dioxide and the utilization of organic compounds in the sea. Thiosulfate-stimulated microbial activity may not be caused only by chemoautotrophic sulfur bacteria, but also by hetero-

trophic species which oxidize thiosulfate to tetrathionate. Measurements of dark assimilation of carbon dioxide made at different incubation times indicate that great care must be taken both in experimental procedure and in interpretation of results obtained with the dark assimilation technique.

In press: *Microbial Ecology*.

Supported by: NSF Grant DES 75-15017.

ROLE OF BACTERIA IN AN UPWELLING ECOSYSTEM

Stanley W. Watson

In this study, using the ATP, LPS and chlorophyll *a* techniques it was demonstrated that bacteria comprise 50% of the total biomass in the oceans. In inshore waters 90% of microbial activity occurs in the sediment but in offshore waters the major site of microbial activity is within the water column.

Supported by: ERDA E(11-1)3656, Arthur Vining Davis Foundation.

PHYSIOLOGY

THE EFFECT OF HYDROSTATIC PRESSURE ON LIGAND BINDING TO HEMOGLOBIN

Francis G. Carey, Francis Knowles and Quentin H. Gibson

Increase in hydrostatic pressure to 1000 atmospheres increased the affinity of human and menhaden (*Brevoortia tyrannus*) hemoglobins for oxygen. With necessary assumptions about the form of the equilibrium curve, and after correction for changes in pH and volume due to pressure, the increase in affinity is about two-fold for both hemoglobins. At pH 6.5, Hill's *n* for menhaden hemoglobin is near 1, and it is believed to remain in the T-state, whereas human hemoglobin undergoes a T to R transition. This suggests that the R-T equilibrium is not disturbed by pressure. In direct experiments the binding of a fluorescent effector (8 hydroxy 1,3,6-pyrene (visulfonic acid) to deoxyhemoglobin was not changed by pressure. The binding of *n*-butylisocyanide to hemoglobin and to myoglobin is also greater at high pressures, similarly suggesting that the R-T transition is not involved in the pressure effect.

Supported by: NSF Grants BMS 74-082322 and GB-38272; and U.S. Public Health Service GM 14276

REVERSE TEMPERATURE DEPENDENCE OF TUNA HEMOGLOBIN OXYGENATION

Francis P. Carey and Quentin H. Gibson

At a pH around 7.5 with 0.05 M NaPi, the shape of the oxygen equilibrium curve of hemoglobin from the bluefin tuna (*Thunnus thynnus*) is temperature dependent. The affinity at low saturation increases, and that at high saturation decreases on cooling from 20° to 10°. The equilibrium curves at the two temperatures therefore cross over. This behavior is physiologically advantageous to a warm-bodied fish. It may be explained in terms of the two-state model by supposing that the allosteric constant *L* increases markedly on cooling the solutions.

Supported by: NSF Grant BMS 74-08233.

PHYTOPLANKTON

GROWTH AND COMPETITION OF THE MARINE DIATOMS *Phaeodactylum tricornutum* Bohlin AND *Thalassiosira pseudonana* Hasle AND Heimdal. I. NUTRIENT EFFECTS.

Christopher F. D'Elia, Robert R.L. Guillard and David M. Nelson

Two marine diatoms, *Phaeodactylum tricornutum* Bohlin and *Thalassiosira pseudonana* Hasle and Heimdal, were grown separately and together in batch culture on a waste water-sea water mixture enriched with different components of f-medium. At 17°C, the maximum division rates of the two species were statistically indistinguishable. The waste water-sea water mixture used proved to have insufficient Si, relative to N and P, for the growth of *T. pseudonana*, which requires approximately 5×10^{-14} g-atoms Si.cell⁻¹ to divide at maximum rate. *P. tricornutum*, on the other hand although capable of taking up nearly 9×10^{-15} g-atoms Si.cell⁻¹, could sustain maximum rates of division with 4.3×10^{-18} g-atoms Si.cell⁻¹ or less. No allelopathic interaction between the two species could be detected. We conclude that *P. tricornutum* enjoys considerable competitive advantage over *T. pseudonana* in a waste water-sea water based mariculture system that is not supplemented with Si. Although Si was proven necessary for *T. pseudonana* to compete more successfully with the other diatom, the presence of excess amounts of Si is not necessarily sufficient for the maintenance of *T. pseudonana* in mixed continuous culture with *P. tricornutum*. Other factors such as light-related or photoperiod-related growth response are believed to determine the ultimate outcome of competition between these algae in light-limited continuous culture.

Supported by: NOAA Sea Grant 04-6-158-44106, NSF Grant OCE 76-10876, Jessie Smith Noyes Foundation and WHOI Postdoc. Fellowship.

ACCUMULATION OF SILICON BY THE NON-SILICON
REQUIRING MARINE ALGA *Platymonas*

J.A. Fuhrman, S.W. Chisholm, Robert R.L. Guillard

The role of silicon in living systems is only recently becoming understood. Aside from its widely known requirement as an important structural component in diatoms and silico-flagellates, some freshwater flagellates, higher plants, sponges and other organisms, this element has been shown to be necessary for DNA polymerase activity in diatoms and for bone and tooth development in certain vertebrates. Silicified algal species are known (or assumed) to have an obligate, concentration dependent, silicon requirement for growth and transport systems for the accumulation of silicic acid ($\text{Si}(\text{OH})_4$) have been described; however, uptake of $\text{Si}(\text{OH})_4$ by non-silicified algae has never been reported. Here we report the accumulation of significant amounts of silicon by the planktonic marine alga *Platymonas* sp., (isolated summer 1954, Great Pond, Falmouth, Mass.). This species is very close to, or may be an isolate of, *P. suecica* (personal communication, R. Norris) and has no known silicon requirement, growing equally well in Si-rich and Si-poor environments. Since $\text{Si}(\text{OH})_4$ is a potentially limiting nutrient for diatoms, the removal of available $\text{Si}(\text{OH})_4$ from the environment by organisms that do not require it, could play an important role in phytoplankton competition and succession.

Supported by: NSF Grants DES 75-15023,
OCE 77-08999 and OCE 76-10876.

STEADY STATE GROWTH AND AMMONIUM UPTAKE
OF A FAST-GROW MARINE DIATOM

Joel C. Goldman and James J. McCarthy

We cultured a fast-growing marine diatom *Thalassiosira pseudonana* (3H) under NH_4^+ -limited steady state conditions in continuous culture. Growth rate could not be described as a function of external or residual NH_4^+ because of analytical limitations in measuring NH_4^+ concentrations $< 0.03 \mu\text{g-atoms N-liter}^{-1}$. Neither did the data fit the internal nutrient model of Droop because the wash out growth rate ($\hat{\mu}$) under N-limitation is substantially less than the maximum growth rate term used in the Droop expression ($\bar{\mu}$). The ratio of the minimum (k_Q) to the maximum (Q_m) cell quota was the key term in determining the ratio $\hat{\mu}:\bar{\mu}$, and hence the applicability of the Droop expression. For limiting nutrients such as vitamin B_{12} and P $\hat{\mu} \sim \bar{\mu}$, and the expression is applicable; but when $\hat{\mu} < \bar{\mu}$, such as for N and Si, the usefulness of the expression is diminished, and when $\bar{\mu} \rightarrow \infty$, as for inorganic carbon, the Droop equation is completely

invalid. In a general sense the usefulness of the Droop expression diminishes as the limiting nutrient:cell weight ratio increases. In addition, we question the generality of the concept of cell "shift up", or increasing k_Q and $\bar{\mu}$ with increasing growth rate, as we could not find any evidence for this phenomenon in *T. pseudonana*. Moreover, the demonstration of discontinuities in kinetic curves of Q vs μ does not *a priori* imply that the coefficients k_Q and $\bar{\mu}$ are variable.

In press: *Limnology and Oceanography*.

Supported by: ERDA CONTRACT E(11-1)2532
and NSF Grant OCE 75-14781.

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

Lynda S. Murphy

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

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

GROWTH AND COMPETITION OF THE MARINE DIATOMS
Phaeodactylum tricornutum AND *Thalassiosira*
pseudonana. II. LIGHT LIMITATION.

David M. Nelson, Christopher F. D'Elia,
and Robert R.L. Guillard

The marine diatoms *Phaeodactylum tricornutum* (Bohlin) and *Thalassiosira pseudonana* (Hasle and Heimdal) were grown under both continuous illumination and a 14:10 hr light:dark cycle at light intensities ranging from 1.53×10^{-4} to $2.95 \times 10^{-1} \text{ ly} \cdot \text{min}^{-1}$. Under both photoperiods *T. pseudonana* exhibited higher division rates than *P. tricornutum* at high light intensities, but the reverse was true at all light

intensities $3 \times 10^{-3} \text{ ly} \cdot \text{min}^{-1}$. Comparison of these results with available data on light-limited growth of other planktonic algae suggests that *P. tricornutum* may be unusually efficient at maintaining its cell division rate at low light intensity. This efficiency may contribute substantially to its success in turbid, nutrient-enriched mass algal culture systems, the only environments in which it is known to attain great numbers.

Supported by: NSF Grants OCE 76-10876, OCE 76-82070; Jessie Smith Noyes Foundation, WHOI Postdoc. Fellowship.

PHOTOACOUSTIC SPECTROSCOPIC ANALYSIS OF MARINE PHYTOPLANKTON

Peter B. Ortner and Allan Rosencwaig
(Bell Laboratories)

The 500-800 nm spectra of replicate phytoplankton cultures freeze-dried upon glass fiber filters were determined both by photoacoustic spectroscopy (PAS) and by photoelectric absorption spectrophotometry. A number of the features of biological interest are more distinct in the PAS spectra. Further, PAS is sufficiently sensitive that it could be applied in the analysis of readily obtainable field samples.

In press: *Hydrobiologia*.

Supported by: ONR Contract N00014-66-C-0241, NSF Grant GA-002783 and Tai Ping Foundation.

UNEXPECTED RESPONSE TO VITAMIN B₁₂ OF THE DOMINANT CENTRIC DIATOMS FROM THE SPRING BLOOM IN THE GULF OF MAINE

Dorothy G. Swift and Robert R.L. Guillard

Twelve clones (seven species) representative of centric diatoms dominant in the spring phytoplankton bloom in the Gulf of Maine were isolated and rendered axenic. Genera included were *Thalassiosira*, *Coscinosira*, and *Chaetoceros*. Unlike most centric diatoms studied previously, none of these has an absolute requirement for vitamin B₁₂. However, vitamin B₁₂ (5 ng l^{-1}) stimulated growth of most clones by eliminating or reducing the lag phase and increasing the growth rate. Bloom population densities developed four to 54 days sooner with vitamin B₁₂ present. Several clones tested, when grown with vitamin B₁₂ added, removed more than 80% of the vitamin from the medium. When grown in vitamin-free medium the cells produced 0.01 to 0.7 ng l^{-1} vitamin B₁₂ in the medium.

Supported by: NSF Grant GB-33288 in part.

BIOMASS AND NUTRIENT FLUX MEASUREMENTS ON *Holothuria atra* POPULATIONS ON WINDWARD REEF FLATS AT ENIWETOK, MARSHALL ISLANDS

Kenneth L. Wegg, Christopher F. D'Elia,
and William D. DuPaul

A population survey of the holothurian, *Holothuria atra*, on the interisland coral reefs of Eniwetok revealed average animal densities of about 3 animals m^{-2} in the zone of small coral heads. Median fresh weight was 60 g. The size distribution of these animals was negatively correlated with water velocity along the reef.

Ammonia release rates for three species of holothurians, *H. atra*, *H. difficilis* and *Actinopyga mauritiana* was weight specific. The release of ammonia by *H. atra* on Transect II was equivalent to 9% of the total ammonia exported from the reef proper. The release of phosphorus followed the general rules set for size-metabolism relationships. Nitrogen/phosphorus release ratios are 25:1 for 1 gram fresh weight animals and 42:1 for 60 gram animals. Urea is also released.

Analysis of sediments, gut contents and fecal pellets indicates that *H. atra* is a selective feeder with an assimilation efficiency of about 40%. Dissolution of calcium carbonate by holothurians is estimated to be about $2.3 \text{ g m}^{-2} \text{ day}^{-1}$, equivalent to 25% of the net calcification rate of the reef proper.

Supported by: OIP, NSF Grants GB-24816 to SIO, GA-25866 and GA-35806.

BIOLOGICAL AND CHEMICAL EFFECTS OF CHLORINATION AT COASTAL POWER PLANTS

Joel C. Goldman, Judith M. Capuzzo
and George T.F. Wong

The chemistry of chlorine in seawater is perhaps the most important unanswered question remaining regarding the impact of this toxicant on marine biota. The dissipation of titratable chlorine in seawater is very rapid and occurs in two distinct phases. The first phase is directly attributable to a true organic chlorine demand and the second probably due to the rapid formation of hypobromite followed by its subsequent inorganic decomposition to, as yet, unknown products. The consumptive capacity of seawater for chlorine and the quickly formed hypobromite appears to be limitless.

Chlorination effects on phytoplankton at power plants appear to be a minimal problem compared to effects on larval zooplankton. Entrained phytoplankton exposed to chlorine represent only a small fraction of the standing crop. Phytoplankton recovery can be fairly rapid and chlorine dissipation in the receiving water is relatively fast. In contrast, populations of

larval species that spawn intermittently could be seriously threatened by chlorination. This is particularly true when considering the fact that metabolic activity is seriously affected at chlorine residual levels below the level of detectability (< 0.01 mg/l). In the presence of more persistent and more toxic chloramine compounds the effects of power plants chlorination could be widely felt in the receiving as well as entrained water. Reproductive rates of zooplankton and growth of larvae appear to be seriously retarded after exposure to sublethal chlorine concentrations. Phytoplankton growth rates of recovered cells, on the other hand, do not appear to be permanently affected. The implications of these findings are self-evident and represent perhaps the strongest condemnation of excessive chlorination use at power plants. The practice of dechlorination immediately after entrainment should be given serious consideration for all coastal cooling systems.

In press: "Water Chlorination: Environmental Impact and Health Effects"; Ann Arbor Press.

Supported by: ERDA Contract E(11-1) 2532.

SALT MARSHES

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

Kathryn A. Burns and John M. Teal

The grounding of an oil barge off West Falmouth, Massachusetts, in Buzzards Bay resulted in petroleum hydrocarbon pollution of marsh, bay, and coastal habitats. Marsh surface sediments, deep mud cores, and organisms were analyzed for hydrocarbons one year and up to seven years after the spill. Included in this report is information on the residence time of oil pollution in a New England salt marsh, patterns of incorporation, dissipation and degradation of oil in the marsh ecosystem, and the uptake and fate of polluting hydrocarbons in plant and animal tissues.

Supported by: NSF Grant GA-40987, Victoria Foundation and Bureau of Com. Fish., Fish & Wildlife Grant 14-17-007-1128(G).

INFLUENCE OF ENVIRONMENTAL CONTAMINATION ON CYTOCHROME P-450 MIXED-FUNCTION OXYGENASES IN FISH: IMPLICATIONS FOR RECOVERY IN THE WILD HARBOR MARSH

John J. Stegeman

Levels of hepatic cytochrome P-450 and the catalytic functions benzo(a)pyrene hydroxylase and aminopyrene demethylase were significantly greater in populations of *Fundulus heteroclitus*

sampled from contaminated marshes as compared to those fish from nearby reference marshes. Amino-pyrene demethylase, but not benzo(a)pyrene hydroxylase, was also elevated in fish from one of the reference marshes. The levels of cytochrome P-450 and benzo(a)pyrene hydroxylase were highest in fish from the Wild Harbor Marsh, site of the 1969 FLORIDA spill. A correlation between size (age) and benzo(a)pyrene hydroxylase activity was identified in some of the populations studied, although influence by this factor did not mask the population differences. The results are consistent with the hypothesis that elevated levels of mixed-function oxygenase activity in fish from Wild Harbor are the result of oil spilled eight years ago, and that recovery of this marsh is not yet complete.

Supported by: NOAA Sea Grant 04-6-158-44106 and NSF Grant OCE 76-84415.

NITROGEN BUDGET OF A COASTAL MARINE ECOSYSTEM

John M. Teal and Ivan Valiela

Nitrogen is the nutrient most often limiting for biological production in coastal marine waters. We present the first attempt to construct a complete nitrogen budget for a coastal marine system, a salt marsh in Massachusetts, U.S.A. The major sources of nitrogen entering the marsh are dissolved organic, inorganic and particulate nitrogen carried by flooding tidal waters. Nitrogen fixation by bacteria and blue-green algae also furnishes substantial nitrogen, with precipitation and flow of ground water providing small contributions. Ebbing tidal waters carry the major nitrogenous losses, with additional significant losses through denitrification. Losses to sediments and volatilization are small.

The total inputs of nitrogen are somewhat smaller than the total exports, in agreement with our finding that production by marsh plants is nitrogen limited. Tidal water is the major export mechanism, providing a variety of nitrogenous compounds to nitrogen-poorer deeper waters.

All the mechanisms of import and export of nitrogen have seasonal variations that can be related to other aspects of the marsh ecosystem, evidencing the interrelation of the nitrogen cycle with the function of an ecosystem.

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

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

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

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

In press: *Fisheries Res.Bd.of Canada*.

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INPUTS, OUTPUTS AND INTERCONVERSIONS OF
NITROGEN IN A SALT MARSH ECOSYSTEM

Ivan Valiela and John M. Teal

The amount of available nitrogen is critical for many important components of salt marsh ecosystems. Several studies have shown that primary producers in salt marshes are N-limited (Tyler, 1967; Pigott, 1969; Valiela and Teal, 1974). The morphology of *Spartina alterniflora* (Valiela *et al.*, 1975; Valiela *et al.*, 1976) are strongly influenced by the supply of nitrogen. We also have data showing that the nitrogen content of marsh grasses provided with added N is greater, and consequently the quality of this fertilized grass as a herbivore food is increased (Caswell *et al.*, 1973). As a result, the biomass of herbivores is also influenced by nitrogen supply (Vince *et al.*, in preparation).

The decomposer food web is also altered by the nitrogen supply. Measurements of oxygen uptake in fertilized plots of marsh grasses show that decomposition rates are enhanced where N was added, probably as a response to the lowered C/N ratios of the detritus produced by death of the fertilized grasses. The increased microorganismal fauna and flora associated with the enriched detrital particles has led to increased biomass of detritus-feeding invertebrates in the fertilized plots.

We also have evidence that fish and other predators that feed on the detritus feeders have increased growth rates. There are many other parts of a salt marsh that are affected by the nitrogen supply. The above examples suffice to show that, at least in Great Sippewissett marsh where we are carrying out our studies, nitrogen seems to be a keystone nutrient, responsible for establishing rates of activity and standing crops of most of the ecosystem. Before we can delve into the intricacies of just how nitrogen (probably in combination with other factors) determines rates, we need to have some idea of the supplies and losses, as well as the major pools, of nitrogen. In this paper we present an account of ongoing work on the inputs and outputs of nitrogen in a salt marsh ecosystem and discuss some of the transfers of nitrogen among major components of the salt marsh.

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

THE NATURE OF GROWTH FORMS IN THE
SALT MARSH GRASS *Spartina alterniflora*

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

Spartina alterniflora Loisel, the salt marsh cordgrass, is the dominant plant of salt marshes on the Atlantic coast of North America and may be found in two markedly different growth forms. The tall form may reach two to three meters in height, has few plants per unit area, thick stems and grows on banks of tidal creeks (Fig. 1a). The dwarf form is about 10-40 cm high, grows quite densely and is commonly found on flat marsh sediments (Fig.1b) landward of the tall form.

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

We have been conducting long-term fertilization experiments on plots in Great Sippewissett marsh, Massachusetts. One unexpected result of these enrichment experiments was a shift in plant morphology from a short sward of *S. alterniflora* to vegetation resembling tall form in leaf width, stem diameter and general appearance (Valiela, Teal and Sass,

1975). This paper considers the results from the enrichment studies, evaluating the effects of nutrients on properties of short and tall *S. alterniflora* and attempts to explain the occurrence of the growth forms in the field.

Supported by: NSF Grants GA-28365 and GA-28272 and Victoria Foundation.

TRANSPORT OF NUTRIENTS INTO A SALT MARSH BY PRECIPITATION AND GROUNDWATER FLOW

Ivan Valiela, John M. Teal, Deborah Shafer,
and Suzanne Volkmann

Nutrients can enter or leave tidal salt marshes through microbial processes, flow of surface or ground water, precipitation, and through tidal exchange with the sea. We discuss microbial fixation of nitrogen and denitrification elsewhere (Ban Raalte *et al.*, 1977; Kaplan *et al.*, in prep.). Tidal exchanges are dealt with in another paper (Valiela *et al.*, in prep.). This paper focuses on nitrogen, phosphorus and carbon brought into Great Sippewissett marsh, Falmouth, Massachusetts, by precipitation and flow of fresh ground water into the marsh.

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

COASTAL ZONE CITING OF ENERGY FACILITIES

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

The environmental effects of building and operating various sorts of energy facilities in the coastal zone are reviewed and discussed. The emphasis is on electric power plants and petroleum-related facilities. It is concluded that such environmental effects can be large and severe, but proper planning can greatly reduce them. Nonetheless, the rapidly increasing development of the coastal zone with centralized, high-technology energy facilities may have a severe impact on coastal resources.

In press: *Ann. Rev. of Energy*.

Supported by: WHOI Graduate Fellowship.

EFFECTS OF NITROGEN ENRICHMENT ON GROWTH RATE AND PHYCOCOLLOID CONTENT IN *Gracilaria foliifera* AND *Neogardhiella baileyi*.

James A. DeBoer

Unattached, free-floating plants, were grown in continuous flow culture systems which received seawater enriched with 0-70 μM ammonium and 0-14 μM phosphate. Growth rate was measured every three days, and agar and carra-

geous content, at the termination of experiments lasting three to four weeks. Agar content in *Gracilaria foliifera* (Forsskal) Borge- sen ranged between 25% of the salt-free dry weight, in the plants receiving the highest concentration of nitrogen fertilizer, and 45%, in the plants receiving unenriched seawater. Carrageenan content in *Neogardhiella baileyi* (Harvey dx Kutzing) Wynne and Taylor was highest (36% of the salt-free dry weight) at nitrogen concentrations in the range of 0.5-1.0 μM ammonium and was lower at both higher ammonium concentrations and in unenriched seawater. The application of these results to the farming and harvesting of agarophytes and carrageenophytes is discussed.

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WASTE WATER RENOVATION

IONIC DISTRIBUTION IN A SPRAY-IRRIGATION SYSTEM

Patricia L. Deese, Ralph F. Vaccaro,
Bostwick H. Ketchum, Paul C. Bowker,
Mark R. Dennett

Several aspects of a $3\frac{1}{2}$ year spray-irrigation and cropping study on Cape Cod are examined. Emphasis is focused on the ionic variation in ground water, soil water, soil, roots and harvested crops during the course of the study.

Crop yield as well as the uptake of N, P, Cu^{++} , Na^+ , K^+ , Mg^{++} , Zn^{++} , Pb^{++} , Cd^{++} , Mn^{++} , Fe^{+++} and Ca^{++} have been shown to be linearly proportional to the total amount of irrigation applied. Breakthrough into the ground water varies with ionic species and has proven much less predictable. Except for chlorides, the ionic concentrations monitored in the ground water do not reflect the establishment of steady-state conditions since the beginning of irrigation. Ground-water concentrations of NO_3^- and Mg^{++} have been decreasing after attaining an initial peak. No significant changes in PO_4^{--} concentration in the ground water have been observed but ground-water concentrations of B, Ca^{++} , and Na^+ are still on the increase. Fluctuations in the ground-water concentrations of other ions, including several heavy metals appear to be random and independent of our experimental variables. This is consistent with the fact that the total amounts of Zn^{++} , Pb^{++} , Mn^{++} , Cd^{++} , and Fe^{+++} applied, remain small compared to the amounts already present in the soil.

At an irrigation rate of 7 cm/week, the time required for a particle of water to reach ground-water level has been estimated to be about 200 days. For lower application rates,

this requirement is significantly larger. Estimates of recharge rates indicate a good recovery of the applied hydraulic load.

Supported by: EPA Contract S-802037.

CONTROLLED CHLORINATION IN AGRICULTURAL SYSTEMS
IRRIGATED WITH SECONDARY SEWAGE EFFLUENTS

Alicja W. Mann, Ralph F. Vaccaro
and Patricia L. Deese

The effects of chlorine on the rates of inactivation of experimentally added MS-2 coliphage have been observed in repetitive field studies of a secondary effluent/spray-irrigation system. Seasonal comparisons are made between the effectiveness of chlorine disinfection and the temperature, pH and ammonia content of the irrigation water at the time of chlorination. Multiple regression analysis of the pertinent data has led to the isolation of statistically reliable mathematical expressions which appear to uniquely quantify the chlorination process at our facility. These relations suggest a useful means of identifying safe but sane dosages of chlorine that minimize the adverse environmental effects of superfluous chlorination yet satisfy public health requirements for pathogen control.

Supported by: EPA S-802037.

ZOOPLANKTON

CONTROLLED ECOSYSTEM POLLUTION EXPERIMENT
EFFECT OF MERCURY ON ENCLOSED WATER COLUMNS
IV. ZOOPLANKTON POPULATION DYNAMICS
AND PRODUCTION

John R. Beers, Michael R. Reeve
and George D. Grice

The taxonomic composition and abundance of the total zooplankton populations contained in three large-volume (1,335 m³) enclosures (Controlled Experimental Ecosystems) in Saanich Inlet, British Columbia were studied over a 72-day period (May 11 - July 21, 1976) during which (on Day 9) inorganic mercury was introduced into two of the enclosures at nominal concentrations of 5 and 1 µg l⁻¹ (CEE 5 and CEE 1). Immediately following mercury addition the zooplankton populations declined in the CEE with the higher mercury level, but differences between the Control and CEE 1 remained relatively small both in total numbers and proportional taxonomic composition. In the two latter CEEs large increases of herbivore occurred as a consequence of nutrient additions and lack of predator pressure. CEE 5 populations also showed increases, but not on the scale of the other two CEEs, and developed different dominant forms. Both the original

decrease and failure of the copepods *Pseudocalanus* and *Acartia* to subsequently increase their populations rapidly were attributed to direct effects of mercury, although the possibility of food quality affecting some of the various observed population fluctuations were not discounted. When mercury level had subsided in CEE 5, some protozoan taxa with short generation times equaled or exceeded the abundance attained in the other CEEs. As a consequence of the few predators present and the correspondingly low mortality of copepod developmental stages it was possible to compute the production of *Pseudocalanus* and *Acartia*, the two copepods comprising the bulk of the mesoplankton. For CEE 1 and the Control, at least 29% and 18%, respectively, of the primary production apparently was converted to the next higher trophic level.

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Supported by: NSF Grant OCE 74-05054.

LIMITS OF *Nematoscelis megalops* IN THE
NORTHWESTERN ATLANTIC IN RELATION TO GULF
STREAM COLD CORE RINGS: PART II. PHYSIOLOGICAL
AND BIOCHEMICAL EFFECTS OF EXPATRIATION.

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

Samples of *Nematoscelis megalops* taken from the same Ring at six and nine months after its formation showed a gradual weakening of their physiological and biochemical condition. Deterioration of Ring individuals is evidenced by an increase in body water content and a reduction in total body lipid carbon, respiration rates and nitrogen relative to Slope Water individuals. By six months it appears Ring *N. megalops* must supplement food intake by metabolizing some of their body protein and by nine months they appear to use lipids as well.

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THE EFFECTS OF FREE CHLORINE AND CHLORAMINE
ON GROWTH AND RESPIRATION RATES OF LARVAL
LOBSTERS (*Homarus americanus*)

Judith M. Capuzzo

The length, dry weight and standard respiration rate of larval lobsters (*Homarus americanus*) were monitored for 19 days following a 60-minute exposure at 25°C to 1.0 mg/l applied free chlorine and 1.0 mg/l applied chloramine. Compared to control organisms, significantly lower increases ($P < 0.05$) in dry weight and significant reductions ($P < 0.01$) in standard respiration rates were measured among

exposed organisms; greater differences were detected among chloramine-exposed organisms. From these results it can be concluded that acute exposure to either free chlorine or chloramine results in subsequent reductions in growth and metabolic activity of larval lobsters.

In press: *Water Research*.

Supported by: *ERDA Contract E(11-1)2532*.

HAIR FAN PATTERNS IN THE CHAETOGNATHA

David L. Feigenbaum

Chaetognaths are important marine predators which rely on external sensory hairs to receive prey-produced vibrations, enabling them to recognize and locate their food. Hair-fan patterns are mapped for both larvae and adults of *Sagitta hispida*, *Sagitta enflata*, and *Spadella schizoptera*, for several sizes of *Sagitta elegans*, and for adults of *Spadella cephaloptera*. The fans are arranged in regular transverse and longitudinal rows with the pattern species-specific, but similar, for all species studied. Larvae possess relatively long hair fans at hatching and the number of fans increases with size in the species of *Sagitta*, but is constant in juveniles and adults of the species of *Spadella*. The maps provide a basis for future studies necessary for a better understanding of the function of these hairs.

In press: *Canadian J. of Zoology*.

Supported by: *NSF Grant OCE 74-12510 A02*, and *Doctoral thesis, Univ. of Miami*.

THE DEVELOPMENTAL STAGES OF A SPECIES OF *Corycaeus* (COPEPODA: CYCLOPOIDA) FROM SAANICH INLET, BRITISH COLUMBIA

Victoria R. Gibson and George D. Grice

The postembryonic development of a species of the cyclopoid copepod genus *Corycaeus* from Saanich Inlet, British Columbia is described and illustrated. Specimens were obtained from a large (40,000/m³) population of *Corycaeus* which developed in the control (unperturbed) enclosure of a Controlled Ecosystem Pollution Experiment studying the effects of copper on marine ecosystems. Population dynamics of the species in the 1700 m³ enclosed water columns are discussed.

In press: *Canadian J. of Zoology*.

Supported by: *NSF Grant IDOE GX-42580*.

Candacia giesbrechti, A NEW CALANOID COPEPOD FROM THE MEDITERRANEAN SEA

George D. Grice and Thomas J. Lawson, Jr.

A new species of *Candacia* is described from specimens obtained in the western Mediterranean Sea.

In press: *Vie et Milieu*.

Supported by: *NSF Grant OCE 74-12604*.

CONTROLLED ECOSYSTEM POLLUTION EXPERIMENT: EFFECT OF MERCURY ON ENCLOSED WATER COLUMNS: VIII. SUMMARY OF RESULTS.

George D. Grice and David W. Menzel

A summary is presented of the results of seven papers describing the effects of mercury on marine ecosystems during a 1976 CEPEX experiment conducted in large (1300m³) plastic enclosures. These papers appeared in issues 3(4) and 4(1) of *Marine Science Communications*.

Major effects of mercury on bacteria, phytoplankton, zooplankton and fish are summarized, as well as the metal chemistry. This experiment is compared to earlier experiments in small (68m³) CEPEX enclosures. Primary differences include the improved survival of upper trophic levels; and the lower predation pressure on the zooplankton, which permitted better characterization of pollutant effects. It is suggested that one recurrent phenomenon in CEE experiments - the rapid displacement of chain-forming centric diatoms by an assemblage of microflagellates - is more related to the stress of containment in enclosures than to pollution.

In press: *Marine Science Communications*.

Supported by: *NSF Grant OCE 76-80249*.

ON THE NATURAL HISTORY AND DISTRIBUTION OF OCEANIC CTENOPHORES

G. Richard Harbison, Laurence P. Madin and Neil R. Swanberg

Oceanic ctenophores show a great diversity in feeding biology, ranging from *Leucothea multicornis* which can eat only small copepods, to species of *Ocyropsis*, which are able to capture and ingest small fish and euphausiids. Cydippids capture prey with tentacles, while lobate ctenophores employ tentacles, mucus, and in some cases, muscular activity. *Eurehamphaea verilligera* feeds much as neritic lobates do, while *Leucothea multicornis* has elaborate oral lobes, which can function independently. *Ocyropsis crystallina* and *O. maculata* both feed by trapping prey with their muscular oral lobes, without use of mucus or tentacles. Cestids feed by trapping small prey on tentacles that lie over the sides of the body. We have collected these

and other species of oceanic ctenophores on about 70% of the 200 dives we have made over the past two years, and we have observed them in densities over 1 per meter³. Our collections, from the North Atlantic and Indian Oceans, show that ctenophores are often dominant predators in the upper waters of the open ocean. Since most species described in this paper are never reported from plankton collections, they constitute a hitherto ignored component of the open ocean ecosystem. Their large size and extreme delicacy make them impossible to collect with conventional sampling techniques, so alternative methods must be devised. Several genera of hyperiid amphipods are closely associated with ctenophores, both as parasites and predators. The ctenophore, *Beroe*, and the heteropods, *Pterotrochea* and *Cardiapoda*, are predators on lobate and cydippid ctenophores. We conclude that ctenophores occupy an important place in the community structure of the open ocean, although they are neglected by standard oceanographic sampling methods.

In press: *Deep-Sea Research*.

Supported by: NSF Grants OCE 75-21715, DES 74-19872; NOAA Grant 04-6-158-44072; and U.S. Dept. of Commerce.

PATTERNS AND PROCESSES IN THE TIME-SPACE SCALES OF PLANKTON DISTRIBUTIONS

Loren R. Haury, John A. McGowan
and Peter H. Wiebe

The time and space scales of oceanic plankton patterns are discussed using as a conceptual framework a biological modification of the three-dimensional diagram presented by Stommel (Science 139: 572-576; 1963). Our diagram plots biomass variability against time (1 sec to 10⁴ years) and space (1 cm to 10⁴ km). The diagram illustrates the overlapping hierarchy of patterns present on the diagonal from small to large time and space scales. There are regions present on this diagonal of particularly large variability; these define focal points for future investigations into the causal processes associated with these patterns. While the spatial patterns in the diagram are based on total plankton biomass, emphasis is placed on the importance of determining patterns at the species (or functional) level. Space scales of pattern are categorized (micro, fine, coarse, meso, macro, mega) and examples given of plankton and nekton distribution for the various scales. The generation, maintenance, and observation of plankton patchiness is discussed, as well as the ecological significance of pattern on scales of less than 1000 km.

Presented at: NATO Advanced Study Inst.
on Plankton Patchiness, Nov., 1977.

Supported by: NSF Grants OCE 77-08682 and OCE 77-09132.

Bathocyroe fosteri: A NEW MESOPELAGIC CTENOPHORE OBSERVED AND COLLECTED FROM A SUBMERSIBLE

Laurence P. Madin and G. Richard Harbison

Observations during four dives in the submersible *Alvin* in June 1976 revealed that ctenophores were the most abundant large plankters between 400-700 m. Specimens of these ctenophores were collected with a slurp-gun device, and described as a new genus and species - *Bathocyroe fosteri*, characterized by strong lobes, large auricles and red pigmentation of the gut.

Published in: *J. Marine Biol. Assn. U.K.*

Supported by: NOAA Grant 04-6-158-44072.

Thalassocalyce inconstans, NEW GENUS AND SPECIES, AN ENIGMATIC CTENOPHORE REPRESENTING A NEW FAMILY AND ORDER

Laurence P. Madin and G. Richard Harbison

Thalassocalyce inconstans is an unusual, medusa-shaped ctenophore collected in slope water off the coast of New England. It is morphologically distinct from both cydippid and lobate ctenophores, and forms the basis of a new order of the Ctenophora, Thalassocalycida. Similarities to previously described medusoid larvae of ctenophores suggest a recapitulation of the Thalassocalycid morphology in the ontogeny of other species.

In press: *Bull. of Marine Science* 28(4).

Supported by: NSF Grants DES 75-21715 and DES 74-19782; NOAA Grant 04-6-158-44072.

PHYTOHYDROGRAPHY AND HERBIVORE HABITAT CONTRASTS IN THE WESTERN NORTH ATLANTIC

Peter B. Ortner, Edward M. Hulburt
and Peter H. Wiebe

The Gulf Stream is a major ecological discontinuity separating two distinct phytohydrographic provinces: the Slope Water and the Northern Sargasso Sea. Contrasts between the two are minimal beneath well-established seasonal thermoclines. Due to systematic differences in the quality, quantity, distribution, variability of their phytoplankton communities, the upper euphotic zones of the Slope Water and the Northern Sargasso Sea represent very different herbivore habitats. Although the Northern

Sargasso Sea has been thought to be a relatively monotonous biogeographic province, within its geographic boundaries, Gulf Stream cold core rings constitute large-scale floral inhomogeneities. Such rings can markedly differ in species composition from both the Slope Water and the Northern Sargasso Sea and are rarely intermediate. Species group ecotypes isolated by correspondence analysis differ in respect to their apparent environmental preferences.

Supported by: *ONR Contracts N00014-66-CO242 and N00014-24-C0262:NR 083-004; NSF Grant DES 74-02783 A01; Tai Ping Foundation and WHOI Grad. Education Program.*

*VARIABILITY IN ZOOPLANKTON BIOMASS
DISTRIBUTION IN THE NORTHERN SARGASSO:
THE CONTRIBUTION OF GULF STREAM COLD-CORE RINGS*

Peter B. Ortner, Peter H. Wiebe,
Loren H. Haury and Steven Boyd

The scale and frequency of physical variability resulting from incursion of Gulf Stream Cold Core rings into the Northern Sargasso Sea makes this faunal province more heterogeneous than previously recognized. At any one time such rings may cover between 6 and 13% of the surface area of the Northern Sargasso Sea. They are more productive than the surrounding Sargasso Sea and have a zooplankton biomass intermediate between the Sargasso Sea and the Slope Water. Cold-core rings may augment by 3% to 7% the primary productivity and by 8% to 16% the zooplankton standing crop of the Northern Sargasso Sea. Compared to either the surrounding Sargasso Sea or their parent Slope Water, an unusually large percentage of the 0-800 m biomass in rings is found at depths greater than 200 m. This distribution can be related to hydrographic and biological changes associated with ring decay. Due to their higher productivity, to difference in vertical biomass structure and to the possibility that ring food chain efficiency is lower than that of the Sargasso Sea, rings may provide a disproportionately large fraction of the total supply of organic matter to the Northern Sargasso deep-sea.

In press: *Fishery Bulletin.*

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*THE SOUTHERN LIMIT OF Nematoscelis megalops
IN THE NORTHWESTERN ATLANTIC IN RELATION TO
GULF STREAM COLD-CORE RINGS: PART I.
HORIZONTAL AND VERTICAL DISTRIBUTION.*

Peter H. Wiebe and Steven H. Boyd

The hydrographic limit of the distribution of *Nematoscelis megalops* in the Northwestern Atlantic Ocean is usually marked by the abrupt changes in water properties across the Gulf Stream. There are, however, isolated but repeated occurrences of this species in the Sargasso Sea. In our study, individuals in the Sargasso Sea were expatriates from the Slope Water which had been transported to the collection site by Gulf Stream cold core rings with but two exceptions. The exceptional cases can be indirectly linked to the presence of rings.

Expatriated populations do not persist. Extinction in a ring appears to take place in one or two generations, and for *N. megalops* it is related to changes in hydrographic properties, and in particular, the vertical temperature structure. In both the Slope Water and in the ring 50% or more of the population is found in a restricted temperature regime centered about 10°C. As a ring ages, the preferred temperature regime and *N. megalops* along with it move deeper into the water column. The physiological and biochemical data given by Boyd, Wiebe and Cox (1977) combined with data given here indicate that withdrawal from the surface results in progressive deterioration of the nutritional condition of the population, a cessation of growth, a drastic reduction in the number of males relative to females, reproduction incapacitation, and ultimate extinction. It is conceivable that a process similar to that occurring in rings is responsible for the maintenance of the Gulf Stream as a hydrographic limit in the distribution of *N. megalops*.

Supported by: *ONR Contracts N00014-66-C-0240 and N00014-24-C-0262:NR 083-004 and NSF Grant DES 74-0283 A01.*

*DIEL VERTICAL MIGRATION BY Salpa aspera:
POTENTIAL FOR LARGE-SCALE PARTICULATE
ORGANIC MATTER TRANSPORT TO THE DEEP-SEA*

Peter H. Wiebe, Laurence P. Madin,
Loren R. Haury, G. Richard Harbison,
and L. Maybelline Philbin

In midsummer 1975 throughout the western Slope Water of the North Atlantic, massive numbers of *Salpa aspera* performed a diel vertical migration of at least 800 m. Fecal pellet production and losses from the population were estimated to contribute at least 8 mg C m⁻² day⁻¹ to the bottom. This represents well over 100% of the daily deep-sea benthic energy requirements.

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*HORIZONTAL DISTRIBUTION OF PUMPED ZOOPLANKTON
DURING A CONTROLLED ECOSYSTEM POLLUTION
EXPERIMENT: IMPLICATIONS FOR SAMPLING STRATEGY
IN LARGE-VOLUME ENCLOSED WATER COLUMNS*

Isabelle P. Williams, Victoria R. Gibson
and Woolcott K. Smith

A large-volume pump system was used to collect zooplankton samples from several locations in three 1300 m³ plastic enclosures (CEEs) in Saanich Inlet, British Columbia. The horizontal distribution of three groups of zooplankton (*Pseudocalanus*, *Oithona* and copepod nauplii) was analyzed. Although the distribution of the organisms was demonstrated to be non-random, tests failed to show any consistent pattern of abundance. It was concluded that the horizontal distribution of zooplankton in the CEEs was not significantly influenced by the location of the sampling position (side of enclosure vs. center, etc.); or by any external factor, such as weather condition.

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1977. (Also refer to Page OE-8)

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CHEMISTRY

C-i

DEPARTMENT OF CHEMISTRY
Derek W. Spencer, Chairman

GEOCHEMISTRY

GEOCHEMISTRY OF FOSSIL FUEL HYDROCARBONS
IN MARINE SEDIMENTS: SELECTED ASPECTS

John W. Farrington

Three investigations are described which illustrate recent advances in analytical chemical and geochemical research on fossil fluid hydrocarbons in the marine environment.

First: The application of quantitative gas chromatography-mass fragmentography to measure selected aromatic hydrocarbons in marsh and coastal sediments. Instrument precisions of 2 to 3% for 50×10^{-9} naphthalene and 1-methylnaphthalene are achieved. The detection limit for naphthalene (signal/noise ratio of 2:1) is estimated to be 5×10^{-11} g/g dry weight of sediment with 25-50 g dry weight of silt-clay coastal sediments. Using this method No. 2 fuel oil aromatic hydrocarbons incorporated into marsh sediments were precisely measured in samples taken within one week of a spill and eight months after a spill.

Second: Several sections from a core in Buzzards Bay, Massachusetts have been analyzed for alkanes, cycloalkanes, and aromatic hydrocarbons. This is an initial attempt at investigating an historical record of anthropogenic fossil fuel inputs to coastal sediments. The results indicate an increase of an order of magnitude in concentrations of fossil fuel hydrocarbons from circa 1810 to 1840 to the present. The aromatic hydrocarbon distributions indicate urban air hydrocarbons as the major source.

Third: The input of fossil fuel hydrocarbons from sewage sludge and dredge spoils in the New York Bight is discussed. An estimated 3.6×10 tons of fossil fuel hydrocarbons are discharged each year by dumping in this area.

Supported by: EPA Grant R803902.

HYDROCARBONS IN CORES OF NORTHWESTERN ATLANTIC
COASTAL AND CONTINENTAL MARGIN SEDIMENTSJohn W. Farrington, Nelson M. Frew,
Philip M. Gschwend and Bruce W. Tripp

The concentrations and composition of hydrocarbons in sections from a ^{210}Pb dated core from Buzzards Bay, Massachusetts are reported. Terrigenous n-alkane concentrations remain constant throughout the 62 cm and 195 years samples. Gas chromatographic analysis on SCOT columns revealed an unresolved complex mixture of alkanes and cycloalkanes which decreases in concentration with increasing depth. Phenanthrene and C_1 and C_2 substituted phenanthrene concentrations decreased with increasing depth and the relative abundance of C_1

and C_2 homologs compared to phenanthrene suggest a pyrolytic origin for these aromatic hydrocarbons.

The various sources of hydrocarbons in surface sediments and the processes which could govern their distribution are discussed. The most likely source of the phenanthrenes and the unresolved complex mixture of alkanes and cycloalkanes in the upper core sections circa 1900 to the present seems to be urban air fallout. A depth distribution of alkanes and cycloalkanes similar to the Buzzards Bay core was found for a second area of Buzzards Bay and for cores from sediments of the Gulf of Maine and Hudson Canyon.

Two C_{25} cycloalkenes were identified as major hydrocarbons in the sediments. Their concentrations decrease with increasing depth in the cores. Mass spectra of these compounds and their hydrogenation products are reported.

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SEDIMENTARY POLYCYCLIC AROMATIC HYDROCARBONS:
THE HISTORICAL RECORDRonald A. Hites, Robert E. LaFlamme
and John W. Farrington

Polycyclic aromatic hydrocarbons (PAH) in three sections of a dated sediment core from Buzzards Bay, Massachusetts, have been analyzed by gas chromatographic mass spectrometry. This historical information suggests that sedimentary PAH, at least in this location, primarily result from the anthropogenic combustion of fossil fuels.

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MASS FRAGMENTOGRAPHIC DETERMINATION OF AROMATIC
HYDROCARBONS IN MARSH AND COASTAL SEDIMENTS

Nelson M. Frew and John W. Farrington

Quantitative gas chromatography-mass fragmentography has been applied to the determination of selected aromatic hydrocarbons in marsh and coastal sediments. Concentrations of phenanthrene and its C_1 and C_2 -substituted homologs are found to decrease by an order of magnitude with depth in a coastal sediment core section representing two hundred years of deposition. Homolog to parent ratios suggest a recent pyrolytic source for these hydrocarbons. Analysis of oil-contaminated marsh sediments show significant losses of

more soluble aromatics (naphthalenes) by water solubilization, dispersal, and redistribution over a six-month interval.

Supported by: *EPA Grants R-802724 and R-803902.*

*THE CYCLING OF LABILE ORGANIC COMPOUNDS:
STEROLS IN THE NORTH ATLANTIC OCEAN*

Robert B. Gagosian

Seawater samples collected from the continental shelf and slope waters of the western North Atlantic Ocean and Sargasso Sea have been analyzed for a class of biogenic compounds, the sterols. The sterol concentrations found ranged from 0.1 to 1.3 $\mu\text{g}/\ell$ seawater. Cholesterol is the major free and esterified sterol in both the surface and deep water. β -Sitosterol, fucosterol, brassicasterol, 22-dehydrocholesterol, campesterol, 24-methylenecholesterol, norcholestadienol and stigmasterol are found in lower concentrations at the surface and in the deep sea. Several sterols, e.g. brassicasterol, appear to be produced and consumed in the upper 1000 m of the water column, whereas few sterols, e.g. cholesterol, were found in the entire water column and may be examples of more resistant organic compounds.

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

Published in: *Oceanic Sound Scattering Prediction*, Ed. by Neil R. Anderson, and Bernard J. Zahuranec (Plenum Press, 1977).

Supported by: *N.S.F. Grant GA-4422 and Sea Grant (22-2000).*

*THE CYCLING OF BIOGENIC COMPOUNDS AND THEIR
DIAGENETICALLY TRANSFORMED PRODUCTS IN SEAWATER*

Robert B. Gagosian and Daniel H. Stuermer

Results are presented for two studies concerned with the sources, transport and trans-

formation mechanisms of two classes of organic compounds. An emphasis is placed on the importance of collecting and correlating related chemical and oceanographic data with the qualitative and quantitative organic compound analyses. The first study involves the analysis of seawater samples for a class of relatively labile, biogenic compounds, the sterols. From the vertical profiles of the sterols, together with hydrographic, particulate organic carbon, and total particulate matter data, an attempt is made to understand sterol distributions in the ocean and the transport mechanisms governing their movement into the deep sea. The second study involves the analysis of Sargasso Sea water samples for a class of more resistant, transformed biogenic compounds, humic and fulvic acids. Their isolation, structural elucidation, mechanism of formation and fate are discussed.

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*STERENES IN SURFACE SEDIMENTS FROM THE
SOUTHWEST AFRICAN SHELF AND SLOPE*

Robert B. Gagosian and John W. Farrington

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

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

The formation of sterenes from sterols via microbiological processes or chemical auto-oxidation, followed by subsequent dehydration mechanisms and double bond isomerizations are postulated.

Supported by: *ONR Contract N00014-66-CO241: NR083-004 and NSF Grant OCE74-09991.*

CHARACTERIZATION OF BITUMENS AND COALS

John M. Hunt

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

Supported by: *Mobil Foundation and the Chevron Oil Field Research Company*

HYDROCARBON STUDIES IN DEEP OCEAN SEDIMENTS

John M. Hunt

The outer continental margins and deep ocean basins are the last major frontiers for petroleum exploration. The Continental Rises contain possibly half of the world's total volume of sediment, but little is known of their hydrocarbon potential.

Light gasoline range hydrocarbons are being analyzed in deep sea cores to determine if the hydrocarbon-forming process in the deep ocean is comparable to that of inland seas and shallow shelf area. Initial results indicate the processes are comparable. A wide range of hydrocarbons is forming in trace amounts at sea-bottom temperatures and the yields increase with increasing depth of burial. It is believed that oil will be found in economic amounts in deep ocean sediments where temperatures reach the main oil generating range of 60 to 150°C.

Supported by: NSF Grant OCE73-06575,

STEROL DIAGENESIS IN RECENT SEDIMENTS
FROM BUZZARDS BAY, MASSACHUSETTSCynthia Lee, Robert B. Gagosian
and John W. Farrington

Sections of a 42 cm core from one area and surface sediments from two other areas of Buzzards Bay, Massachusetts were analyzed for sterols. The distribution of sterols in surface sediments appears to be influenced by benthic faunal composition or factors controlling this composition. A comparison of sterols extracted by Soxhlet-extraction with sterols extracted after subsequent saponification of the sediment showed that the former sterols decrease in concentration while the latter saponified sterols increase in concentration with depth. In both fractions, the individual sterol compositions are similar. A transformation between Soxhlet-extractable and non-Soxhlet-extractable saponified sterols appears to be occurring over the 130 years sampled by the core. This transformation is probably due to chemical/physical processes rather than biological processes. Comparison with fatty acid data shows that early diagenesis of sterols is slower than early diagenesis of fatty acids.

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CADMIUM, COBALT, COPPER, IRON, MANGANESE,
NICKEL AND LEAD IN INTERSTITIAL WATER
COLLECTED *in situ* IN DEEP SEA SEDIMENTS

Michael J. Orren and Frederick L. Sayles

A new technique which determines cadmium, cobalt, copper, iron, manganese, nickel and lead at the ppb level in a 2 ml sample was used to estimate metal concentrations in interstitial water samples collected by an *in situ* probe in deep-sea sediments at five stations between Africa and Antarctica. The average manganese diffusive flux of 1.6×10^{-16} g/cm²/sec is lower than recent estimates by Elderfield (1976) and Manheim (1976). The other elements showed wide fluctuations, but mean values were generally in good agreement with other recent data. Estimates of the flux of cadmium, copper and lead from sediments into the ocean agreed within an order of magnitude with the world river input of these elements.

Supported by: NSF Grant OCE77-81620.

EASTERN INDIAN OCEAN DSDP SITES: CORRELATIONS
BETWEEN PETROGRAPHY, GEOCHEMISTRY AND
TECTONIC SETTINGFred A. Frey, John S. Dickey, Jr.,
Geoffrey Thompson and Wilfred B. Bryan

At 10 and 13 Deep Sea Drilling Project (DSDP) sites in the eastern Indian Ocean there is a correlation between inferred tectonic history and the petrographic and geochemical nature of basement basalts. Compositions of unaltered glasses and phenocrysts, in addition to abundances of Ti, Zr, and rare-earths in crystalline rocks, are used to determine the geochemical characteristics of magmas erupted at each site. At Sites 212, 213, 257, 259, 260 and 261, the basalts are within the compositional range of large ion lithophile (LIL) element-depleted tholeiites dredged from spreading ridge axes, such as the mid-Indian Ocean Ridge. These results are consistent with tectonic models indicating a seafloor spreading origin for basement basalt at these sites. In contrast, the alkali-olivine basalts at Site 211 are probably related to volcanism creating the nearby Cocos, Keeling and Christmas Islands.

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

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

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TRACE ELEMENT MOBILITY DURING HYDROTHERMAL ALTERATION OF OCEANIC BASALTS

Susan E. Humphris and Geoffrey Thompson

Trace element analyses have been carried out on hydrothermally altered pillow basalts of greenschist facies dredged from the median valley of the Mid-Atlantic Ridge. Sr is leached from the rock, and its behavior is apparently controlled by the same reactions as Ca. Cu is also leached from the basalt, but often shows local precipitation in veins as sulfides. Fe, B, Li, Ba, Mn, Ni, and Co show sufficient variations in concentration and location within the altered basalts to indicate that some mobilization occurs, but there may be subsequent uptake or precipitation into the secondary mineral assemblages. V, Y, Zr and Cr do not appear to be affected by hydrothermal alteration.

The production of a metal-enriched solution by hydrothermal alteration and subsequent precipitation of metal salts to form metalliferous sediments is indicated, as is precipitation of metal sulfides in the basaltic basement.

In Press: *Geochimica et Cosmochimica Acta*.

Supported by: NSF Grant OCE74-22971.

HYDROTHERMAL ALTERATION OF OCEANIC BASALTS BY SEAWATER

Susan E. Humphris and Geoffrey Thompson

Hydrothermally altered pillow basalts dredged from the Mid-Atlantic Ridge, and belonging to the greenschist facies, have been studied in order to determine the mineralogical, and corresponding chemical changes, that result from basalt-seawater interaction at elevated temperatures.

The mineralogical transformations are predominantly to albite-actinolite-chlorite-epidote assemblages. Quartz and pyrite are common accessory minerals. On the basis of their mineralogy, the samples may be divided into chlorite-rich and epidote-rich assemblages. The chlorite-rich assemblages, which are the predominant variety, show the greatest chemical changes, while the epidote-rich samples show very little change in composition compared with their basaltic precursors.

Mass balances across individual pillows in which the central portions are relatively unaltered allow the directions and ranges of elemental fluxes to be calculated. In general, SiO₂ and CaO are leached from the basalt, while MgO and H₂O are taken up. No consistent trends are observed for Na₂O and K₂O although they do show some variations in the core-and-rim analyses.

Consideration of the elemental fluxes in terms of the steady-state geochemical mass balances for oceanic inputs and outputs indicates that hydrothermal alteration provides a sink for Mg, which may be extremely important in solving the problem of apparent excess Mg input to the oceans. The amount of Ca that is leached from the rock may be of significance in the geochemical budget of that element. The amount of SiO₂ in the circulating fluid is controlled by the solubility of quartz or amorphous silica, depending on temperature, and considerable redistribution of silica takes place within the basaltic pile. The changes in redox conditions during hydrothermal alteration do not affect the present day oxidation state of the atmosphere and hydrosphere.

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OLDEST ATLANTIC SEAFLOOR:
MESOZOIC BASALTS FROM WESTERN NORTH ATLANTIC
MARGIN AND EASTERN NORTH AMERICA

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

Basalt recovered beneath Jurassic sediments in the western Atlantic at Deep Sea Drilling Project Sites 100 and 105 of Leg 11 has petrographic features characteristic of water-quenched basalt extruded along modern ocean ridges. Site 100 basalt appears to represent two or three massive cooling units, and an extensive emplacement is probable. Site 105 basalt is less altered and appears to be a compositionally homogeneous pillow lava sequence related to a single eruptive episode.

Although the Leg 11 basalts are much more closely related in time to the Triassic lavas and intrusives of eastern continental North America, their geochemical features are closely comparable to those of modern Mid-Atlantic Ridge basalts unrelated to postulated "mantle plume" activity. Projection of Leg 11 sites back along accepted spreading "flow lines" to their presumed points of origin shows that these origins are also outside the influence of modern "plume" activity. Thus, these oldest Atlantic seafloor basalts provide no information on the time of initiation of these "plumes". The Triassic continental diabases show north to south compositional variations in Rb, Ba, La, and Sr which lie within the range of "plume"-related basalt on the Mid-Atlantic Ridge (20°-40°N). This suggests that these diabases had mantle sources similar in composition to those beneath the present Mid-Atlantic Ridge. "Plumes" related to deep mantle sources may have contributed to the LIL-element enrichment in the Triassic diabase and may also have been instrumental in initiating the rifting of the North Atlantic. Systematically high values for K and $\text{Sr}^{87}/\text{Sr}^{86}$ in the Triassic diabassic may reflect superimposed effects of crustal contamination in the Triassic magmas.

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SEAWATER - ROCK INTERACTIONS
IN THE OCEANIC BASEMENT

Geoffrey Thompson and Susan E. Humphries

Seawater - basaltic rock interactions at elevated temperatures ($>100^\circ\text{C}$) result in significant uptake of Mg and loss of Ca, Si, alkaline and transitional metals by the rock. The reaction is important in the geochemical mass balance of the oceans, particularly acting as a major sink for magnesium ($1 - 10\text{g MgO}/100\text{cm}^3$ basalt). It also has importance in other

elemental cycles and metal precipitation. Weathering reactions of basalt and seawater at ambient bottom temperatures are slow, but result in significant uptake of K, P, Rb, Li, B, Cu and Zn. This reaction may be a major sink for potassium ($0.7 \times 10^{-9}\text{g K}_2\text{O}/\text{cm}^3$ basalt/year). It is not significant in direct ore formation.

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

Jonathan Stebbins and Geoffrey Thompson

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

Supported by: NSF Grant OCE74-22971.

COMPOSITIONAL VARIATION IN A STEADY-STATE
ZONED MAGMA CHAMBER: MID-ATLANTIC RIDGE
AT $36^\circ 50' \text{N}$

Wilfred B. Bryan and Geoffrey Thompson

Basalt glass collected in the FAMOUS dive area by the submersible *Alvin* have been analyzed for B, Li, Cr, Ni, Co, Cu, Ga, S, Ba, V, Y, and Zr by optical emission spectrography. Field relations, petrography, and other published trace element data are revised. Published partition coefficients are combined with least-squares estimates of mineral proportions to compute variation expected for postulated equilibrium crystallization in a high-level, zoned magma chamber. Variation in Cr, Ni, Co, and Cu is consistent with such a process, involving crystallization of plagioclase, pyroxene, olivine, and sulphide. The other elements are enriched by factors from about 1.5 to 4.0 times the amounts predicted by this model; the excess enrichment is greatest for Ba and least

for Y and V. These excess enrichments may in part reflect the progress accumulation of incompatible elements in the margins of a steady state magma chamber, and may also reflect variations in initial concentrations in successive batches of mantle-derived parent liquid.

Supported by: *NSF Grant OCE75-00294.*

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

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

Ferrobasalts from DSDP Sites 214 and 216 on the 90°E ridge are characterized by: high absolute iron (FeO 12.9 wt.%; FeO/MgO 1.9; TiO₂ 2.0 wt.%). Their trace element abundances indicate a tholeiitic affinity; however, they are distinct from mid-ocean ridge incompatible element depleted tholeiites due to higher contents of Ba, Zr and Sr, and flat to slightly light-REE enriched chondrite-normalized REE patterns.

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

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COMPOSITION OF EIGHT APOLLO 17 BASALTS

Brian Mason, E. Jarosewich,
Sara Jacobson and Geoffrey Thompson

Chemical analyses, Cross-Iddings-Pirsson-Washington norms, and mineralogical and petrographical data are presented for eight mare basalts collected on the Apollo 17 mission. Seven of these have very similar chemical compositions but can be divided into two textural groups: medium to coarse grained (70017, 71055, 74255, 75075) and fine grained (70215, 71569, 74275). The eighth, 75035, has a distinctive chemical and mineralogical composition (lower titania, higher silica, quartz in the norm, and cristobalite in the mode), and evidently represents a different flow probably underlying the high-titanium basalts at Camelot Crater.

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*BASALTS AND RELATED ROCKS FROM DEEP SEA
DRILLING SITES IN THE CENTRAL AND EASTERN
INDIAN OCEAN*

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

Petrological and geochemical data are presented for basement rocks recovered from thirteen sites (211, 212, 213, 214, 215, 216, 253, 254, 256, 257, 259, 269 and 261) drilled on Legs 22, 26 and 27 of the Deep Sea Drilling Program. Basalts from Sites 212, 213, 253, 257, 259 and 261 have petrographic and geochemical characteristics of tholeiitic basalts from active spreading ridge axes in the major ocean basins.

Except for the lower basalts at Site 253, all the basement rocks from four Ninetyeast Ridge sites (214, 216, 253, 254) are similar to oceanic island tholeiitic sequences such as on Amsterdam-St. Paul Islands. The geochemical data for the Ninetyeast Ridge rocks are consistent with the development of this ridge as a hot-spot trace.

Basalts from deep ocean Sites 216 and 256 have geochemical characteristics more akin to tholeiitic basalts from spreading ridge axes close to major volcanic islands, i.e. they have high large ion lithophile element abundances relative to tholeiitic basalts found at spreading ridge axes away from islands.

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C₁ TO C₇ HYDROCARBONS FROM IPOD HOLE 397/397A

Jean K. Whelan

Gases from sediment pockets were monitored on shipboard during continuous coring to a depth of 1453 m. Gas pockets first appeared at a sediment depth of 80 m and continued irregularly to the bottom of the hole. The gas contained small quantities (0.1 to 1.3%) of methane from 30 to 124 m with major components of air and CO₂. The order of H₂S was noted in the cores from 9 m to 151 m. Starting at 96 m, methane became a significant component (43%) and then varied irregularly from 1-81% of the gas throughout the rest of the hole. A gas chromatograph installed on shipboard at the beginning of Leg 47A allowed monitoring of traces of C₂-C₅ hydrocarbons in gas pockets. These hydrocarbons, which included 3 to 2000 ppm of C₂ by volume, 1 to 140 ppm of C₃, 0.1 to 25 ppm of C₄ and 0.1 to 4 ppm of C₅, were found along with the methane throughout the hole. The C₁-C₅ hydrocarbon levels followed lithologic changes to a remarkable degree with proportions of C₂:C₃:C₄:C₅ staying relatively constant in fine-grained sediments and with the (C₁ + C₂)/(C₃ + C₄ + C₅) ratio increasing erratically in coarser-grained sediments and in most of the hole unconformities. This indicates hydrocarbons were migrating from fine-grained source beds to coarse-grained reservoir beds and along the more permeable unconformities throughout the hole. Ratios of i-C₅/n-C₅ and i-C₄/n-C₄ appeared to vary with changes in organic source material. Traces of neopentane occurred irregularly and are probably indicative of terpene-derived material. Sediment C₁-C₇ analysis showed that only traces of C₆ and C₇ hydrocarbons were present above 800 m. Below 800 m the C₆ and C₇ hydrocarbons generally increased with sediment depth and age.

Supported by: NSF Grant OCE73-06575.

C₂-C₇ HYDROCARBONS FROM IPOD HOLE 398D

Jean K. Whelan and John M. Hunt

Levels of both organic carbon and C₁-C₇ hydrocarbons in Hole 398D were generally low. The levels of specific compounds were erratic. However, the number of detectable different hydrocarbon isomers and the total amount of C₂-C₇ was larger in deeper clay/claystone Cretaceous sediments below 1050 m than in younger nanno ooze/siliceous nanno ooze sediments above 800 m, possibly due to the larger organic matter content of the former.

In press: *Init.Repts.of the Deep Sea Drilling Project, Vol.47.*

Supported by: NSF Grant OCE73-06575.

SEDIMENT C₁-C₇ HYDROCARBONS FROM IPOD LEG 48 - BAY OF BISCAY

Jean K. Whelan and John M. Hunt

Six core samples from about equal depths (300-400 m) but different geologic ages were examined for C₁-C₇ hydrocarbons. Two of the three Cretaceous samples from Hole 402-A showed high organic carbon content (2.3-2.4%) but low yields of C₄-C₇/C₀. The deepest sample from this site showed lower organic carbon, but higher C₄-C₇/C₀. Three younger samples (Eocene) from Sites 403 and 404 showed low amounts of organic carbon (0.1 to 0.2%) but generally higher yields of C₄-C₇/C₀.

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Supported by: NSF Grant OCE73-06575.

SEDIMENT C₁-C₇ HYDROCARBONS FROM IPOD LEG 44 - (MOROCCAN BASIN)

Jean K. Whelan and John M. Hunt

Hydrocarbon yields from early Cretaceous (Hauterivian/Valangian) cores from Site 416A (1119 m to 1532 m depths) were 0 to 38 ng (C₄ + C₅)/g dry weight of sediment and 2.1 to 28.2 ng (C₆ + C₇)/g dry weight of sediment. Two samples with low organic carbon values showed moderate levels of C₄-C₇ and high levels of (C₄ + C₅)/C₀. These values may indicate migrated hydrocarbons. One shallow lower Miocene sample from Site 415 (210 m) showed very low levels of C₁-C₇ in spite of moderate organic carbon content (0.9%).

Supported by: NSF Grant OCE73-06575.

SEAWATER CHEMISTRY

*CONSUMPTION OF DISSOLVED METHANE
IN THE DEEP OCEAN*

Mary I. Scranton and Peter G. Brewer

Oceanic dissolved methane concentrations are normally in excess of atmospheric equilibrium values in surface waters but show a rapid decrease with depth. Deep North Atlantic waters have only ca. 30% of their atmospheric equilibrium values of methane and deep North Pacific waters have only ca. 10%. We have calculated methane consumption rates based upon methane analyses and water mass ages derived from published data on $^3\text{H}/^3\text{He}$ ages, ^{14}C ages and model calculations. The results show that both methane and oxygen are rapidly consumed in 'young' water but, while oxygen consumption continues at a low rate throughout the deep ocean, methane consumption virtually ceases within about 100 years of isolation from the surface ocean.

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*EVIDENCE FOR AND RATE OF DENITRIFICATION
IN THE ARABIAN SEA*Werner G. Deuser, Edith H. Ross,
and Zofia J. Mlodzinska

Results from a recent cruise in the Arabian Sea show a clear association of the secondary nitrite maximum with the intermediate salinity maximum originating in the Persian Gulf and Gulf of Oman. During its spreading through the Arabian Sea, the Persian Gulf core layer mixes with water of higher nitrate content and lower oxygen content. Reduction of nitrate to nitrite and beyond, occurs at dissolved oxygen concentrations below about $7\mu\text{M}/\ell$ and is restricted to a well-defined area of the northern Arabian Sea. The original nitrate concentrations can be calculated from the salinity-nitrate relationship in waters outside this area. This, in turn, allows determination of a combined-nitrogen deficit, i.e. the amount of nitrate reduced beyond nitrite. Based on limits of the spreading rate of the Persian Gulf core layer through the Arabian Sea, a range for the denitrification rate of 10^{11} to 10^{12} g N yr^{-1} was determined. This is equivalent to about 1%, to a maximum of 10%, of the global rate required for maintenance of a steady state in the distribution of nitrogen at the surface of the earth.

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

*EXCESS ^3He AND ^4He IN GALAPAGOS
SUBMARINE HYDROTHERMAL WATERS*

William J. Jenkins

Recently discovered submarine hydrothermal waters issuing from crevices in the Galapagos Spreading Center contain large enrichments in helium with a characteristically high ($^3\text{He}/^4\text{He}$) isotopic ratio. The observed linear correlation of the concentration of this anomalous helium with the temperature of the waters is used to estimate the global hydrothermal convective heat flux to be $4.9 \pm 1.2 \times 10^{19}$ cal/g.

Supported by: NSF Grant OCE76-00389.

*A SEMIAUTOMATED PERSULFATE OXIDATION
TECHNIQUE FOR SIMULTANEOUS TOTAL NITROGEN
AND TOTAL PHOSPHORUS DETERMINATION
IN NATURAL WATER SAMPLES*Patricia M. Glibert, Christopher F. D'Elia
and Zofia Mlodzinska

A semiautomated method for the determination of total nitrogen and total phosphorus in natural waters couples a manual alkaline persulfate digestion with Technicon AutoAnalyzer methodology. In the 0-25.00 μg atoms N liter $^{-1}$ range, nitrogen recovery was quantitative, with a standard error of 0.29 μg atoms N liter $^{-1}$ on duplicates. Phosphorous recovery was also quantitative, with a standard error on duplicates of 0.045 μg atoms P liter $^{-1}$.

Supported by: ERDA Contract E(11-1)-2948,
the Jessie Noyes Smith Foundation and
the OIP of W.H.O.I.

*A COMPARISON OF TWO BUFFER SYSTEMS USED IN
THE STANDARD METHOD FOR THE DETERMINATION
OF NITRATE IN SEAWATER*

Patricia N. Glibert and Zofia J. Mlodzinska

The use of NH_4Cl as a buffer in the standard method of nitrate analysis in seawater is shown to be preferable over the frequently used EDTA buffer because it results in greater nitrate to nitrite reduction and high precision.

Supported by: ONR Contract N00014-74-C0262:
NR083-004, and OIP of W.H.O.I.

*CHEMICAL FLUXES FROM A SEDIMENT TRAP EXPERIMENT
IN THE DEEP SARGASSO SEA*

Derek W. Spencer, Peter G. Brewer, Alan Fleeer,
Susumu Honjo, S. Krishnaswami and Yoshio Nozaki

Two sediment traps, each with an opening of 1.5 m^2 , were deployed at 5367 m in 5581 m of water at $31^{\circ}34'N, 55^{\circ}03'W$ in the Sargasso Sea. The traps were located within the bottom nepheloid layer, which, at this site, extends from about 4900 m to the bottom. The two traps collected different amounts of material. In a collection of 75 days, the mean total particulate flux is estimated to be $1.68 \pm 0.79 \text{ mg cm}^{-2} \text{ yr}^{-1}$.

Samples from each trap have been analyzed for the elements Si, Al, Ca, K, Mg, Fe, Mn, Ba, Sr, Ti, V, I, Sc, La, Cr, Sb, Cu, Zn, Cd, Ni and Co by a combination of instrumental neutron activation and atomic absorption techniques. Several radioisotopes, including ^{234}Th , ^{228}Th , ^{230}Th , ^{232}Th , ^{210}Po , ^{210}Pb , ^{227}Th , ^{238}U and ^{226}Ra , have been determined by α and β spectrometry. The trapped material consists of about 50% clay, 20% calcium carbonate, 20% silica and 5% organic matter.

We interpret the elemental and isotope data to suggest that, of the total flux, only 5% of the clay, most of the calcium carbonate and 90% of the organic matter were contributed by rapidly settling large particles, derived recently from the surface ocean. The largest part of the total flux appears to be from resuspended bottom sediments that are aggregated and sedimented from the nepheloid layer, probably by a population of benthic-pelagic organisms that produce distinct red fecal pellets consisting of about 80% clay.

The flux of resuspended bottom sediment complicates the interpretation of the U-Th series isotope data. In particular, the measured mean flux of ^{230}Th is 14% less than that expected from production in the overlying water column. However, the existence of a major flux of ^{230}Th from resuspended sediment means that either the traps are inefficient for fine particles that may contain most of the flux of the ^{230}Th or that adsorption onto settling particles may not be the major removal mechanism for ^{230}Th in the deep ocean.

The measured fluxes of the long-lived nuclides ^{232}Th , ^{230}Th , ^{238}U and ^{226}Ra are consistent with the suggestion that about 60% of the total mass flux is derived from resuspended bottom sediment.

Most of the measured flux of the short-lived nuclides, ^{234}Th , ^{228}Th , ^{210}Pb and ^{210}Po must be derived from the water column above the trap. We have derived a model which relates the settling velocity of particles to a first-order adsorption coefficient for the

uptake of nuclides onto particles settling through the water column. On the assumption that the adsorption coefficient is the same for ^{228}Th and ^{234}Th , the model suggests that the residence time for adsorption of Th onto particles may be from 70 years to infinity, depending upon the efficiency with which the total flux of particles is intercepted by the traps, and the settling velocity is about 1.1×10^4 to $4.5 \times 10^4 \text{ m yr}^{-1}$. Adsorption of radionuclides during the transit of the particle flux from the upper layers of the ocean is not necessary to explain our data.

Supported by: NSF Grant OCE76-10514.

PARTICLES AND PARTICLE FLUXES IN THE OCEAN

Derek W. Spencer, Susumu Honjo,
and Peter G. Brewer

It is abundantly clear that the sea floor can no longer be considered as a place remote from the surface. These two regions of the ocean are coupled by a large particle flux which operates at a rate so that the deep ocean floor may respond on time scales of weeks to months to changes that take place in the surface ocean.

Materials introduced into the surface ocean, if they can be taken up by growing plants or adsorbed onto particles, can ride the "fecal express" to the sea floor in a few days. The zooplankton grazing cycles, together with bacterial reactions, form a major filter for the chemical fluxes to the deep ocean. Organic matter and its contained elements are rapidly remineralized in the near surface, but sufficient organic carbon escapes, by means of the accelerated large particle fluxes, to provide food for the benthos. Indigestible materials such as terrigenous dusts, carbonate and silica particles are both fragmented and aggregated by the same zooplankton grazing. The aggregates settle rapidly to the sea floor while the fine fragments of carbonate and silica which escape the aggregation process (i.e. being eaten) will sink slowly and undoubtedly dissolve long before they reach the bottom. Determination of the geographical and depth variations in the large and fine particle fluxes forms an important part of the work to be accomplished in the next several years by marine biologists, chemists and geologists.

Supported by: NSF Grant OCE76-10514.

PRECISION OF GEOSECS SHIPBOARD DATA
IN THE ATLANTIC OCEAN

Derek W. Spencer, Arnold W. Mantyla,
Taro Takahashi, Raymond F. Weiss
and Arnold E. Bainbridge

The utility of any set of data depends, ultimately, on the precision with which that data has been measured. An important part of the GEOSECS program is the acquisition of precisely determined profiles of salinity, temperature, oxygen, nutrients, dissolved nitrogen and argon, total carbon dioxide and alkalinity. All of these constituents have been determined at about 45 depths at 110 stations throughout the Atlantic Ocean section from 75°N to 60°S. Prior to the cruise, targets had been set for the precision that should be attained, generally less than 1.5% coefficient of variation (c.v.) for the nutrients, less than 0.5% c.v. for oxygen, less than 0.2% c.v. for alkalinity, less than 0.5% c.v. for total carbon dioxide, less than 0.003° standard deviation (s.d.) for salinity and less than 0.005°C s.d. for temperature. These targets represented realistic limits that could be approached during routine operations using the best methods available.

Supported by: NSF Grant OCE77-81144.

THE DETERMINATION OF NITRITE IN SEA WATER -
A REVISION CONCERNING STANDARDIZATION

Oliver C. Zafiriou and Mary B. True

The standard solution used in the low level method of Wada and Hattori (1971) is unstable. We recommend using the standard used in the usual method of Strickland and Parsons (1972) instead.

Published in: *Analytica Chimica Acta*, 92:
223-225 (Short Communication).

Supported by: NSF Grant OCE72-01553.

MARINE ORGANIC PHOTOCHEMISTRY PREVIEWED

Oliver C. Zafiriou

Sunlight photolyzes organic compounds in surface waters of the marine environment, destroying some substances and synthesizing others. Such reactions may proceed at high rates and have biological, chemical and geological implications; the subject is in its infancy.

Models are presented that estimate the maximum realistic rates of photochemical transformations at the sea surface and in a 40-meter thick mixed layer; typical rates vary widely and an average cannot be specified. The maximal rates are extremely high at the surface and throughout the layer, corres-

ponding to daylight photodestruction times in the seconds-minutes range. Highly photosensitive materials will thus have vanishingly small steady-state concentrations in surface waters. Actual rates ranging from 1 to 10⁻⁸ times the modelled ones may, depending on the rates of competing processes, be significant in the marine environment. The rate of a photoprocess is the product of the excitation rate for light absorption and the chemical efficiency (quantum yield) of ensuing reactions.

Mechanistic description of marine photo-reactions involves three basic component processes: light absorption, primary photochemical reactions, and secondary reactions. Water, dissolved organic matter, and living and dead particulate matter are the principal absorbers in seawater. The chemical structures of the chromophores involved are not well known, even for the dissolved organic "Gelbstoffe" that color seawater. Most simple organic compounds known in seawater are not effective absorbers. The ensuing reactions of excited states include, beside many specific transformations, general reaction types such as free-radical formation by bond cleavages and by electron transfer redox reactions. Electronic energy transfer also excites other solute molecules.

Both of these general primary process types lead to secondary reactions. It is proposed here that secondary reactions are of general importance in marine photochemistry, that they have a net oxidative character in seawater, and that such reactions may provide one sink for both colored and non-absorbing refractory organic molecules in the marine environment. For chromophores, there may be a self-destroying negative feedback effect. Organic radicals produced directly, or indirectly by interaction with inorganic radicals such as O₂⁻, CO₃⁻, NO, NO₂, OH, and Br₂⁻, are expected to react semiquantitatively with dissolved oxygen, leading to unstable organoperoxy radicals. One photon may thus result in the oxidation of several carbon atoms by short-chain auto-oxidations. Similarly, electronic energy transfer in seawater should result almost exclusively in formation of electronically excited singlet molecular oxygen, a reactive but selective oxidant.

Progress in marine organic photochemistry can be anticipated, but artifacts arising from inappropriate light intensities and wavelengths, trace contaminant effects, and photobiological processes must be avoided. Methods for overcoming these difficulties are available for some solution reactions, but potentially important particulate photochemistry studies are much less tractable. Conceptually, marine photochemistry may develop fruitful ties with solution-free radical and radiation chemistry on the one hand, and optical oceanography and euphotic zone biology and chemistry on the other.

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1977.

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ORGANIC AND BIOLOGICAL CHEMISTRY

AN ATOMIC EMISSION SPECTROMETER/SPECTROGRAPH FOR THE DETERMINATION OF BARIUM IN MICRO-AMOUNTS OF DIATOM ASH

Donald C. Bankston and Nicholas S. Fisher

The development and routine application of a method for the determination of trace levels of barium in micro-samples (5-10 mg) of diatom ash is described. Acid-dissolved lithium metaborate fusion melts of ash samples are analyzed using a spectrometer/spectrograph equipped with a d.c. argon plasma jet excitation source and an echelle diffraction grating. Sample, standard, and blank solutions are buffered by lithium contributed by the flux, to a degree sufficient to reduce matrix effects to acceptable levels. Previous barium determinations by other analytical techniques, on seven interlaboratory reference materials, have been used to establish the accuracy of our results. The average relative standard deviation for the instrumental analyses was 0.07. Using recommended instrument settings, moreover, the lowest concentration of barium visible in synthetic standard solutions lies just below 2 $\mu\text{g/l}$, which is equivalent to 2 $\mu\text{g/g}$ in the ash.

Published in: *Analytical Chemistry*, 49:
p.1017, June, 1977,

Supported by: *ERDA Contract E(11-1)-3563*.

EFFECTS OF POLYCHLORINATED BIPHENYLS ON GROWTH AND RESPIRATION OF HETEROTROPHIC MARINE BACTERIA

Richard P. Blakemore and Anne E. Carey

A number of marine bacterial isolates from both near-shore and open-ocean environs were tested for growth inhibition with exposure to low levels (1-100 $\mu\text{g/l}$) of Aroclor 1254, a commercial mixture of polychlorinated biphenyls (PCBs). Of over 17 bacterial cultures tested, growth of only two open-ocean isolates, one a pseudomonad and the other a tetrad-forming coccus, was consistently inhibited by Aroclor at concentrations as low as 10 $\mu\text{g/l}$ (10 ppb).

Growth inhibition was dose-dependent over a concentration range of 10-100 $\mu\text{g/l}$. The effects upon division rates and final cell yields of each bacterial isolate were greatest when PCBs were added to cultures with low cell densities or with lower specific growth rates. The pseudomonad also had reduced carotenoid levels and an altered filamentous morphology with Aroclor present at 10 $\mu\text{g/l}$, or more.

The effects noted were reversible for at least 18 hours after initial exposure.

Concentrations of Aroclor in excess of that needed to stop growth had no detectable effect upon the respiration rate of cells of either culture. This suggests that the reduced division rates observed were not due to inability of PCB treated cells to transport or catabolize the carbohydrate or amino acid substrates tested.

Supported by: *ERDA Contract E(11-1) 3563*.

RAPID SAMPLING CULTURE CHAMBER FOR ANAEROBIC BACTERIA

Anne E. Carey and Brian W. Schroeder

An all-glass chamber for culturing anaerobic bacteria in liquid medium is described. The system permits both rapid sampling and turbidimetric measurements under controlled atmospheric conditions.

Supported by: *ERDA Contract E(11-1)-3563*.

METABOLISM OF POLYCHLORINATED BIPHENYLS BY MARINE BACTERIA

Anne E. Carey and George R. Harvey

The world's oceans are the final repository in the cycling of polychlorinated biphenyls (PCBs). In order to understand possible long-term effects of PCBs in the marine environment, we have been studying interactions of marine bacteria and PCBs. Mixed cultures of marine bacteria were observed to metabolize PCBs. Aerobic incubation of one liter batch cultures of natural seawater samples with 500 ng to 1 mg PCBs produced metabolism of ^{14}C -2,5,2' trichlorobiphenyl, ^{14}C -2,5,2',5' tetrachlorobiphenyl and ^3H -Aroclor 1254. Two to four percent of the PCBs were metabolized to a carboxylic acid within three days. Increasing the duration of incubation did not increase extent of metabolism, suggesting that the metabolite may be inhibitory to further metabolism. The metabolite is extractable and recoverable from organic solvent with saturated bicarbonate, and is extractable but irrecoverable with stronger base. This suggests that there has been ring opening to a lactone acid or unsaturated acid.

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*FATTY ACID DYNAMICS IN TWO CLONES OF
A MARINE DIATOM: IMPLICATIONS FOR
PHYSIOLOGICAL ECOLOGY*

Nicholas S. Fisher and Rene P. Schwarzenbach

The growth, dry weight, fatty acid weight, and fatty acid composition of two clones of *Thalassiosira pseudonana*, a marine diatom, were measured under several conditions of light, temperature, and nutrient depletion. Qualitative and quantitative determinations of total cellular fatty acids were made using chemical ionization mass spectrometry. Both clones had the same fatty acids, dominated by C14:0 (i.e. 14 C atoms, no double bonds), C16:0, C16:1, C16:3, C16:4, C18:4, and C20:5, though in different relative amounts.

Cellular fatty acids typically represented 5-10% of a cell's dry weight during log phase growth, and increased to as much as 22% during stationary phase. Increasing the temperature from 10 to 18°C had little effect on the fatty acid composition of clone 3H cells. The C16 fatty acids of both clones changed as the cultures aged, though much more markedly in clone 13-1 (Sargasso Sea isolate) than in estuarine clone 3H. Cells of clone 13-1 sustained cell division during a 24-hour dark period while cells of clone 3H stopped dividing after two hours in the dark. The C16:0 and C16:1 acids of both clones declined sharply in the dark and were replenished in the light. When cells had an excess of available energy (constant illumination, no cell division), they produced large quantities of these acids. 13-1 cells treated with PCB, a lipophilic chlorinated hydrocarbon, initially grew more slowly than control cells, weighed more, and had higher relative amounts of C16:0 and C16:1. The results are consistent with the hypothesis that the C16:0 and C16:1 fatty acids are mostly stored in triacylglycerols as energy-rich fuels and that the other acids are predominantly esterified in the polar lipids.

In press: *J. Phycol.*

Supported by: ERDA Contract E(11-1)-3563
and NSF OCE72-22781.

*RAPID DETERMINATION OF THE MOLECULAR WEIGHT
DISTRIBUTION OF TOTAL CELLULAR FATTY ACIDS
USING CHEMICAL IONIZATION MASS SPECTROMETRY*

Rene P. Schwarzenbach and Nicholas S. Fisher

A new method for the qualitative and quantitative determination of the molecular weight distribution of total cellular fatty acids is described. The method includes a simple extraction-saponification followed by chemical ionization mass spectrometric analysis of the saponifiable matter. This technique requires small

quantities of cell material, which, combined with the rapidity and precision of the analysis, makes it attractive to the biologist interested in changes in the fatty acid composition of growing cells. As an example, an application of this method to the fatty acid determination of marine diatoms at different growth stages is presented.

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*FATTY ACID DYNAMICS IN Thalassiosira pseudonana
(BACILLARIOPHYCEAE): IMPLICATIONS
FOR PHYSIOLOGICAL ECOLOGY*

Nicholas S. Fisher and Rene P. Schwarzenbach

The growth, dry weight, fatty acid weight and fatty acid composition of two clones of *Thalassiosira pseudonana* Hasle and Heimdal were measured under several growth conditions. Determinations of total cellular fatty acids were made using chemical ionization mass spectrometry. Both clones had the same fatty acids, dominated by C14:0, C16:0, C16:1, C16:3, C16:4, C18:4 and C20:5, though in different amounts. Fatty acids typically represented 5-10% of the dry weight of a cell during log phase growth and as much as 22% during stationary phase. The C16 fatty acids of both clones changed as the cultures aged, though much more markedly in the Sargasso Sea clone (13-1) than in the estuarine one (clone 3H). The C16:0 and C16:1 acids of both clones declined sharply in the dark and were replenished in the light. Cells maintained in constant illumination, but with no cell division, produced large quantities of these acids. Cells of clone 13-1 treated with polychlorinated biphenyl initially grew more slowly than control cells, weighed more, and had higher relative amounts of C16:0 and C16:1. Fatty acid studies may provide useful indicators of ecologically important energy reserves and membrane adaptations in the algae.

In press: *J. Phycol.*

Supported by: ERDA Contract E(11-1)-3563,
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Swiss Foundation.

RADIOCHEMISTRY

PALEOMAGNETISM AND RADIOCHEMICAL AGE
ESTIMATES FOR LATE-BRUNHES POLARITY EPISODESCharles R. Denham, Robert F. Anderson
and Michael P. Bacon

Several reversed polarity magnetozones occur within deep-sea sediment core CH57-8 from the Greater Antilles Outer Ridge, within sediment of Latest-Pleistocene/Late-Brunhes age. The uppermost reversed interval spanning 31 data points coincides with the X faunal zone of the Last Interglacial Period. Radiochemical dating of cores CH57-8 and KN25-4 has shown that all the reversed polarity magnetozones are significantly younger than the Brunhes/Matuyama boundary at 0.7 m.y. B.P. A variation of the excess ^{230}Th method was used, in which ^{210}Po and ^{238}U were the actual radionuclides measured. In a third core from the Mid-Atlantic Ridge, our ^{210}Po results were similar to those which others obtained earlier by direct ^{230}Th measurements.

Published in: *Earth and Planetary Science Letters*, 35: 384-397. 1977.

Supported by: ERDA Contract AT(11-1)-3566.

WINDSCALE EFFLUENT IN THE WATERS
AND SEDIMENTS OF THE MINCH

Hugh D. Livingston and Vaughan T. Bowen

Analyses of ^{134}Cs , ^{137}Cs , ^{90}Sr , $^{239,240}\text{Pu}$, ^{238}Pu and ^{241}Am are presented for 60 liter seawater samples and a sediment core collected at a station in the Minch, off N.W. Scotland, in May, 1976. The data indicate that the major source of these nuclides at this location is discharge of radioactivity into the Irish Sea from the nuclear fuel re-processing plant at Windscale on the N.W. coast of England. It is concluded that:

1) these nuclides are transported to the Minch from the Irish Sea in the northward coastal current with a net transit time of about two years - the major fraction being spent in the Irish Sea;

2) cesium from Windscale behaves biogeochemically similar to that from fallout;

3) although the major fraction of Windscale discharged plutonium stays in the Irish Sea, the soluble fraction behaves qualitatively like ^{137}Cs in its transport in the coastal current, but that only a fraction (estimated at about one-half) survives travel to the Minch, relative to ^{137}Cs ;

4) that, relative to plutonium, americium sediments rapidly out of the coastal current and a smaller fraction of it reaches the Minch.

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GEOLOGY and GEOPHYSICS

GG-1

DEPARTMENT OF GEOLOGY AND GEOPHYSICS

John I. Ewing, Department Chairman

GEOLOGY

*SURFICIAL SLIDES AND SLUMPS ON THE CONTINENTAL
SLOPE AND RISE OF SOUTH WEST AFRICA:
A RECONNAISSANCE STUDY*

Colin P. Summerhayes, Brian D. Bornhold and
Robert W. Embley

Off South West Africa, a large slide and a large slump have displaced together about 250 km³ of surficial sediment from the lower continental slope onto the upper continental rise. The slide and slump scars together cover an area of about 6000 km²; they affect only the upper few tens of meters of the sediment column. A debris flow extends about 250 km downslope from the slide scar, and deformed sediments extend a similar distance downslope from the slump scar. Apparently both the slide and the slump were triggered during the late Pleistocene, and neither of them gave rise to turbidity currents.

In press: *Amer. Assoc. Petrol. Geol. Bull.*

Supported by: ONR Contract N00014-74-
C-0262; NR 083004.

*THE VARIATION OF BASALT PHENOCRYST MINERALOGY
AND ROCK COMPOSITIONS IN DSDP HOLE 396B*

Henry J.B. Dick and Wilfred B. Bryan

Data on phenocryst proportions and content for basalts representative of the stratigraphic section drilled at DSDP site 396B and olivine and spinel phenocryst microprobe analyses for all basalts are presented. The variations of phenocryst proportions, content and composition with whole rock composition and stratigraphic position of the basalts are used to infer their petrogenesis. Based on the colinearity of aphyric and phenocryst free basalt compositions, crystallization of the site 396B basalts was controlled by a low pressure cotectic. Phenocryst proportions vary irregularly in the basalts indicating that gravity separation of phenocrysts occurred due to flotation of plagioclase and sinking of olivine. The proportion of olivine which must have crystallized from one site 396B unit in order to account for the range in olivine phenocryst composition in the basalts, is the same as that expected from the present plagioclase phenocryst content for crystallization along the low pressure cotectic. Irregular variations in melt composition and fO₂ as suggested by olivine and spinel microphenocryst compositions and the presence of normally and reversely zoned phenocrysts in the same sample suggest periodic mixing of the new magma with old. All these features and the large irregular stratigraphic variation of basalt compositions and mineralogy within a pillow unit can

be explained if the site 396B pillow lavas tapped different portions of a heterogeneous magma chamber. Heterogeneity in the chamber would arise as a consequence of the introduction of new melt and due to gravitational sorting of phenocrysts. The abrupt changes in composition and mineralogy of the basalt and the presence of sediment and weathering at the contacts of the various site 396B pillow basalt units suggest that volcanic activity was periodic at site 396B, possibly triggered or controlled by intermittent earthquake swarm and fissuring along this portion of the old ridge axis. The differences in chemistry and mineralogy of the different units then is probably the consequence of a random combination of fractional crystallization and magma mixing or the formation of a new magma chamber between cycles of volcanic activity.

In press: *Init. Repts. of the Deep Sea
Drilling Project - Leg 46.*

Supported by: NSF Grant OCE 76-21967.

*TECTONIC STRUCTURE AND PETROLOGY OF THE
ANTARCTIC PLATE BOUNDARY NEAR THE
BOUVET TRIPLE JUNCTION*

John G. Sclarer, Henry Dick, Ian O. Norton
and David Woodroffe

An *en echelon* suite of four fracture zones, trending approximately N40°E, has been discovered during a survey of the Southwest Indian Ridge between Bouvet Island and 14°E. The largest of these fracture zones, the Islas Orcadas and Shaka, are less than 30 km wide, have more than 3 km of vertical relief, and are respectively 100 and 200 km in length. The morphology of these and the Bouvet and Prince Edward fracture zones have been used to compute a pole for the relative motion between Africa and Antarctica. This pole, at 4°S and 32°W, is within the range of previously computed pole positions.

Ridge basalts were dredged at three separate locations: at the Conrad Fracture Zone near 55°40'S and 3°51'W, at the Islas Orcadas Fracture Zone near 54°05'S and 6°04'E, and at the ridge crest near 11°E. In addition, samples from a probable upper mantle intrusion were recovered from one wall of the Islas Orcadas Fracture Zone. The opposite wall was very different consisting entirely of normal mid-ocean ridge basalt.

In press: *Earth Planet. Sci. Lett.*

Supported by: NSF Grants OPP76-19053 and
OPP74-12862.

*A NEAR-BOTTOM TRAVERSE OF ROCKALL TROUGH:
HYDROGRAPHIC AND GEOLOGIC INFERENCES*

Peter Lonsdale and Charles D. Hollister

Two profiles with a deeply-towed instrument package provide a broken traverse of geologic and hydrographic data across the southern Rockall Trough. These near-bottom observations are supplemented with airgun profiles, a CTD cast, and current meter data. Symmetric sand ripples at bathyal depths on both margins, which are superimposed on a field of sand waves on the slope of Rockall Bank, are attributed to bed load transport by tidal currents. Abyssal thermohaline currents are inferred from ripples, scour crescents and other indicators on more than 2000 stereo pairs of bottom photographs. In addition to the expected southerly currents on the western side of the trough, which is a passage for Norwegian Sea Overflow, there is evidence for fast, narrow and erosive currents of Labrador Sea Water and Northeast Atlantic Deep Water (NEADW) at the eastern boundary. The northeasterly NEADW current at the foot of the Irish Continental Slope appears to be part of a cyclonic loop which brings silica-rich water into the trough, has built and is now eroding a narrow continental rise, and has transferred much terrigenous debris to the western side of the trough, for deposition along Feni Ridge. Maximum Late Pleistocene deposition on Feni Ridge has been on its northwest flank, beneath a weak reverse (northeasterly) current. On the southeastern flank of Feni Ridge local alternation of slow and fast sediment deposition (probably caused by topographically-induced local variations in current speed of the benthic boundary layer) has created 2 km-wavelength mud waves that migrate up the regional slope at less than 1 m/1000 years.

In press: *Deep Sea Research*.

Supported by: NSF Grants DES 74-03690, DES 74-20396 and OCE 76-21592; ONR Contracts N00014-750-0704 and N00014-75C-0749 to the Marine Physiological Laboratory; and N00014-74C-0262; NR 083-004.

*SUSPENDED MATTER IN SURFACE WATERS:
INFLUENCE OF RIVER DISCHARGE AND OF UPWELLING*

Kenneth O. Emery and John D. Milliman

About 4100 samples of suspended matter were collected by filtration of surface ocean waters in three large regions on the western sides of oceans and two on the eastern sides. Comparison of results shows that the non-combustible fraction (chiefly detrital clays and silts with some siliceous and calcareous skeletal debris) generally dominates along the western sides of

oceans, where large contributions of solid detrital sediment are made by rivers that drain much of the adjacent continents. The combustible fraction also is important off these rivers, but it is more important (both relative to the non-combustible fraction and in absolute terms) along the eastern sides of oceans, where upwelling is intense.

Published in: *Sedimentology*, 24, 1977.

Supported by: NSF Grant GX-28193.

*THE GEOLOGY AND SHORES OF CAPE COD:
FIELD TRIP GUIDE FOR NORTHEAST MARINE
ENVIRONMENTAL INSTITUTION*

Kenneth O. Emery

Discussion and maps of the glacial geology, present topography, depth to basement rocks and depth to water table on the Cape.

In press: *Geology and Shores of Cape Cod*.

Supported by: Henry Bryant Bigelow
Oceanographer Chair.

*ORIGIN OF THE ABYSSAL BASALTIC SAND,
SANDSTONE AND GRAVEL FROM DSDP HOLE 3968, LEG 46.*

Henry J.B. Dick, Jose Honnorez and
Paul W. Kirst

Basaltic sand, sandstone and gravel were recovered at three separate subbasement horizons at DSDP Hole 3968 (Plate 1). Erratic drilling behavior was noticed during penetration of these horizons, at Hole 3968, which were characterized by unusually high drilling rates, and sticking and jamming of the drill bit. This is, to our knowledge, the first time such material has been reported from a DSDP subbasement core. Similar erratic drilling conditions have been reported at other DSDP sites. Thus it appears that similar material may have been drilled at other DSDP sites but no sample was recovered, except at Sites 410, 411 and 413 of Leg 49 where "lumps of basalt came up immersed in a basaltic sand, perhaps a sediment or perhaps drill cuttings" (Summary of DSDP Leg 49).

In Hole 3968, exceptionally high drilling rates through the second sand horizon (43 meters per hour as opposed to 1 to 6 meters per hour in basalt), very poor to non-existent core recoveries in the area of the sands, high porosity logs and the presence of bedded sandstone mixed with the sand in Core 30 raised the possibility that the sands and gravels were not drilling artifacts.

Although not widely recognized, locally derived sands and gravels are a common feature of the abyssal oceanic crust. Sands found in sediment cores from 24 different locations

along the crest of the Mid-Atlantic Ridge have been reported. Accordingly, the recovery of such material while drilling the oceanic crust should not be surprising.

In press: *Init.Repts. of Deep Sea Drilling Project, Leg 46.*

Supported by: *NSF Grant OCE 76-21917.*

BASIC FEATURES OF THE BLACK SEA LATE CENOZOIC HISTORY BASED ON THE RESULTS OF DEEP-SEA DRILLING, LEG 42B

M. V. Muratov, Yuri P. Neprochnov,
David A. Ross and Egis S. Trimonis

The Black Sea is of special interest to geologists and geophysicists because of its unique deep structure and its geological environment. Its connection with the Mediterranean Sea through the relatively narrow and shallow-water Bosphorus Strait was repeatedly interrupted causing sharp changes in the hydrological and hydrochemical regimes, and in the fauna and sedimentation conditions. The DSDP drillings helped explain these important stages in the Black Sea development. The main objectives of the 42B Leg were to obtain as complete as possible Pleistocene stratigraphic section, to collect information concerning the association of the Black Sea with the Mediterranean, and to determine the basic signs of the diagenetic alteration of organic matter. It was also hoped that the drilling would solve a number of particular questions concerning geology, geophysics, geochemistry, biostratigraphy and other fields, and aid in a reconstruction of the Black Sea geological history.

In press: *Init.Repts. of the Deep Sea Drilling Project - Leg 42.*

Supported by: *Deep Sea Drilling Project.*

VISUAL OBSERVATIONS IN SUBMARINE CANYONS OFF THE ISLAND OF MOLOKAI, HAWAIIAN ISLANDS

Neil F. Marshall and Charles D. Hollister

Pelekunu Submarine Canyon on the north side of Molokai appears to have formed by sub-aerial erosion and subsequently subsided about 2,000 meters below sea level. Amikopala Canyon on the south side of Molokai contains a thin sediment fill and large blocks that appeared to be lateral infill float. No evidence of significant downcanyon sediment movement was observed in either canyon.

The existence of a former sea cliff between 1,000-2,000 m and of a submerged terrace below 2,000 m off Molokai is suggested. These correlations and the lack of submarine canyons on the Maui platform indicate that the period of subsidence occurred around 1.25-1.50 million years ago.

Dives aboard the research submersible DSV4 *Sea Cliff* around the Hawaiian Islands of Molokai were made to study various aspects of submarine canyon processes, especially sediment dynamics, in two of Molokai's prominent submarine canyons; Pelekunu (north side) and Amikopala (south side).

In press: *Marine Geology.*

Supported by: *ONR Contracts N00014-69A-0200-6049 and N00014-74C-0262;NR 083-004.*

BLACK SEA STRATIGRAPHY

David A. Ross

This paper presents some details of the stratigraphic nomenclature of Black Sea sediments and short summaries of the relevant paleontological studies performed on sediments collected during Leg 42B. Based on these studies, a consistent and generally acceptable stratigraphy for the drilled Black Sea sediment cannot be established at this time.

In press: *Init.Repts. of Deep Sea Drilling Project - Leg 42*

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

SUMMARY OF RESULTS OF BLACK SEA DRILLING

David A. Ross

The Black Sea, which is one of the largest of the world's marginal seas, is unique in several ways. It is a semi-enclosed basin almost completely surrounded by large alpine mountain ranges: the Pontic Mountains to the south and the Caucasus Mountains to the east and north. Geophysical studies have shown that the Black Sea may contain as much as 17 km of material, that is probably of sedimentary origin, above a basaltic basement. It appears, therefore, that the area has been a sedimentary basin for a considerable period of time -- general estimates are for as long as 200 million years, or back to the Cretaceous. Prior to that time, the Black Sea area was probably a topographic high that supplied sediments to surrounding marginal troughs that were eventually uplifted to form the new surrounding mountain ranges.

In press: *Init.Repts. of Deep Sea Drilling Project - Leg 42.*

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

BLACK SEA GEOPHYSICAL FRAMEWORK

Yuri P. Neprochnov, P.P. Shirshov
and David A. Ross

The Black Sea is one of the largest enclosed marine seas, occupying an area of 432,000 km² and having depths greater than 2 km. This basin, which has sediment thicknesses in excess of 15 km, has been in existence for perhaps 200 million years. Prior to this time it was a topographic high that supplied sediments to adjacent basins that were to be eventually folded into the surrounding Caucasus and Pontic Mountains.

The Black Sea has long been of interest to oceanographers because of its unusual history and environment. It is believed to be a remnant of the Tethys Sea which existed prior to the major splitting and separation of continents some two hundred million years ago. The environment of the Black Sea is also unique in that it is the largest body of anoxic water in the world. From about 100 meters depth to the bottom at 2200 meters, the water contains hydrogen sulfide which is deadly to all forms of life except anaerobic bacteria.

At present the Black Sea has only one opening to the ocean -- the Bosphorus (sill depth about 50 meters). Thus, when the ocean level dropped during Pleistocene glacial interludes, the Black Sea became disconnected from the Mediterranean, and in due course changed from marine to lacustrine conditions. Earlier another link existed, i.e., via the Caspian Sea. Still earlier, other poorly documented links occurred with the Carpathian basins. These openings had a decisive influence on the water chemistry, biological population, and sediment composition of the Black Sea. Since they are climatically controlled, the paleontological record and the geochemistry of the sediments can supply information about regional paleoecology and paleoclimatology.

The main objective of the drilling in the Black Sea was to continuously core the upper 500 meters or more of sediment at two or three selected localities. The sediments obtained have yielded one of the most complete Pleistocene records yet obtained from the ocean. Because the Black Sea has a relatively high sedimentation rate (about 10 cm/1000 yrs.) and is sensitive to sea level changes (because of the shallow sill at the Bosphorus), changes in the level of the sea had a dramatic influence on the sediments and environment of the Black Sea (see following papers in this volume). An indication of this influence was noted from short piston cores, which showed that the Black Sea was a fresh water lake from 22,000 to 9,000 years B.P. when world-wide sea level dropped and isolated it from the Mediterranean Sea. The numerous rivers entering the Black Sea at that

time were sufficient to turn it into a lake.

The purpose of this paper is to present some background data on the geophysical, and to a lesser extent geological, setting of the Black Sea.

In press: *Init. Repts. of Deep Sea Drilling Project - Leg 42.*

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

ISLAND SUBSIDENCE, HOT SPOTS AND LITHOSPHERIC THINNING

Robert S. Detrick and Sperman Thomas Crough

Drilling results from Pacific atolls indicate these islands have subsided much more than would be expected from the cooling and thickening of the underlying lithosphere. This excess subsidence cannot be satisfactorily explained by isostatic adjustments to the weight of the volcano or the coral reef cap. It appears that the islands form atop unusually shallow areas of seafloor, like the Hawaiian swell associated with mid-plate hot spots; and that their excess subsidence is caused by the gradual return of these shallow areas to normal depths. Several authors have suggested that the Hawaiian swell is supported by upward flow in the asthenosphere. However, this model offers no reasonable explanation for the shape of the swell or the observed rates of atoll subsidence. The regional gravity anomaly over the Hawaiian swell indicates that the swell is probably compensated within the lower half of the lithosphere, not within the asthenosphere as would be expected if the swell were maintained by asthenospheric flow. We propose that the Hawaiian swell is formed by lithospheric thinning over the Hawaiian hot spot. Since the asthenosphere is less dense than the lithosphere, replacement of the lower portion of the lithosphere by asthenosphere causes isostatic uplift of the surface of the plate. After the lithosphere moves away from the hot spot, it cools and thickens and the swell subsides. The subsidence histories of the Hawaiian swell and several Pacific atolls are in quantitative agreement with this mechanism. We have assumed that this thinning is caused by high asthenospheric heat flux associated with hot spots, but there are problems with this assumption in that it requires extremely fast rates of lithospheric heating.

In press: *J. Geophysical Research.*

Supported by: *ONR Contract N00014-75-C-0291 and a W.H.O.I. Education Fellowship.*

LOW MARINE TERRACES OF GRAND CAYMAN ISLAND

Kenneth O. Emery

Twenty leveling profiles across the shore zone of Grand Cayman Island reveal the presence of six low marine terraces now above sea level. The lowest and youngest one at about 2-m elevation is the most widespread. Higher terraces are so weathered and eroded that they probably are much older than the 2-m one. The terraces are believed to record stages of Sangamon and earlier interglacial high sea levels superimposed upon tectonic sinking of the island associated with sea-floor spreading in the adjacent Cayman Trough.

In press: *Symposium Vol. on Cayman Trough. Geol. Soc. Amer.*

Supported by: W.H.O.I. Ocean Industry Program and NSF Grant OCE 75-18533.

SEA-FLOOR CURRENTS ON THE FORESET SLOPE OF THE FRASER RIVER DELTA, BRITISH COLUMBIA (CANADA)

Francis P. Shepard and John D. Milliman

Several current meter records from the sea valley on the delta front off the Fraser River show excellent upvalley and downvalley fluctuations in current direction. Both the period and magnitude of the currents fluctuate markedly between spring and neap tides. Near the valley head, (85 m), downvalley flows coincide with ebb tide, while upvalley flows correlate with flood tide; exactly the opposite pattern occurs at a deeper station (220 m), suggesting a five hour eighteen minute time lag in down slope migration of tidally-induced currents.

In press: *Marine Geology.*

Supported by: NSF Grant DES 74-22089 and ONR Contract N00014-69A-0200-6094.

OLDEST ATLANTIC SEAFLOOR: MESOZOIC BASALTS FROM WESTERN NORTH ATLANTIC MARGIN AND EASTERN NORTH AMERICA

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

Basalt was recovered beneath Jurassic sediments in the western Atlantic at Deep Sea Drilling Project Sites 100 and 105 of Leg 11. These basalts have petrographic features characteristic of water-quenched basalt extruded along modern ocean ridges. At Site 100 the basalt is strongly altered by low temperature weathering, precluding detailed inferences about mineralogy and compositional variability, but it appears to represent two or three massive cooling units, and an intrusive emplacement is possible. The basalt at Site 105 is less altered and appears to be a compositionally homogeneous pillow lava sequence related to a single eruptive episode.

Although the Leg 11 basalts are much more closely related in time to the Triassic lavas of eastern continental North America, their geochemical features are closely comparable to those of modern Mid-Atlantic Ridge (MAR) basalts. The compositional differences between the Mesozoic continental and oceanic basalts are especially marked for incompatible elements such as K, Ba, Zr, and light rare earth elements. Both Site 100 and Site 105 basalts have geochemical features characteristic of ocean ridge basalts unrelated to postulated "plume" activity along mid-ocean ridges. Projection of these sites along accepted spreading "flow lines" to their presumed point of origin on the MAR shows that these origins are also outside the influence of modern "plume" activity. Thus, these oldest Atlantic seafloor basalts provide no information on the time of initiation of these "plumes". However, the Triassic continental basalts show north to south compositional variations similar in some respects to those in modern MAR basalts. These data suggest that magmatic processes at the MAR have been similar throughout most of the period of opening of the North Atlantic, and that the Triassic continental lavas may have had mantle sources similar in composition to those beneath the present Mid-Atlantic Ridge. Although the Triassic lavas may represent the first volcanic events associated with the rifting of North America from Africa, these continental basalts must have been modified by contamination and fractionation during extended residence within, or at the base of, the continental crust prior to initiation of rifting. If "plume" activity related to a deep mantle source contributed to the incompatible element enrichment in these basalts, it may also have been instrumental in initiating the rifting of the North Atlantic.

In press: *Contrib. Mineralogy & Petrology, Contrib. #3953.*

Supported by: NSF Grant OCE 75-15858.

THE GEOCHEMISTRY OF CHROME SPINEL IN FAMOUS BASALTS AND MODELS FOR MAGMA GENESIS AT AN OCEAN RIDGE

Henry J.B. Dick

The distribution and mineralogy of basalts from the FAMOUS region of the Mid-Atlantic Ridge suggests that a number of chemically distinct mantle derived magmas have been intruded at different times along the ridge axis. A close examination of the mineralogy of chrome spinel shows two spinel populations in the FAMOUS basalts. The first of these is relatively chrome rich and represents equilibrium crystallization of spinel on the sea floor. The second population is gradational ranging from high alumina spinels to the high chromium varieties. This later group is found exclu-

sively in primitive MgCa basalts, are anhedral, and partially resorbed. They are attributed to high pressure crystallization of spinel during ascent of the MgCa basalts from the mantle. Examination of the mineralogy of other basalt groups from the FAMOUS region suggest intra-group differences may be the result of varying degrees of fractional crystallization during magma ascent. The pseudocotectic defined by FAMOUS basalt glass compositions then is viewed as the trace of the three-dimensional plane defined by the actual cotectic with variable pressure.

In press: *Contrib. Mineralogy and Petrology*.

Supported by: NSF and Oregon Dept. Geology and Mineral Industries.

BASALT FROM 22°-23°,
MID-ATLANTIC RIDGE MEDIAN VALLEY

Wilfred B. Bryan and David Sargent

The petrography and chemical composition of basalt, dolerite and greenstone from the median valley at 22°N were reported by Melson *et al.* (1968). The samples were dredged from various levels on the inner walls of the valley and included significant amounts of mylonitized basalt, greenstone, and dolerite. Melson *et al.* reported major element data for basalt glasses selected from these same dredge stations. During *Atlantis II* Cruise 92, four additional dredge stations were successfully completed at about 23°N. Station 28 was in the rift mountains west of the median valley; station 29 was on the lower slope of the west wall of the valley, and stations 30 and 31 represent material recovered on the eastern and western floor of the valley, respectively. A selection of glass chips representing basalts from each of these stations was analyzed by electron microprobe at the Department of Mineral Sciences, Smithsonian Institution, according to procedures described by Melson *et al.* In this section we summarize the petrography and major element chemistry of the *Atlantis II* collection and compare these data with published data for 22°N and with the preliminary shipboard data for site 395 and 396, in order to define the regional petrologic setting of the Leg 45 basalts.

In press: *Init. Repts. of Deep Sea Drilling Project - Leg 45*.

Supported by: *Internat. Program of Ocean Drilling CU-W.H.O.I.-25903*.

THE BLACK SEA AND THE SEA OF AZOV

David A. Ross

The Black Sea is one of the world's largest marginal seas, with an area of 432,000 km² and a volume of 534,000 km³. Most of the basin is

deeper than 2000 m and the maximum depth reached is 2,206 m. It is connected by a narrow passage, the Kerch Strait, to the shallow Sea of Azov, which has an area of about 36,500 km² (excluding the Sivash or Putrid Sea) and a volume of about 470 km³. The average depth of the Sea of Azov is close to 12 m. Sill depth between the two seas at the Kerch Strait is about 5 m. The Black Sea is connected to the Mediterranean Sea via the shallow Bosphorus (sill depth about 50 m). The Sivash or Putrid Sea is a shallow area separated from the Sea of Azov by a 110-km-long sand bar called the Arabat-kaya Strelka.

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Supported by: NSF Grant GA-25234 and ONR Contract N00014-74-C-0262:NR 083-004.

THE RIFT VALLEY OF THE MID-ATLANTIC RIDGE

Robert D. Ballard and James G. Moore

Approximately two hundred million years ago, the continental nuclei of Europe, Africa, and the Americas began to separate as a result of dynamic processes taking place within the earth. As the land masses moved apart, a large crack or rift zone developed in the Earth's rigid outer layer, the lithosphere. In response to separation of the lithosphere along this zone of rifting, plastic material from the Earth's interior rose toward the surface filling the void. Unlike the light granitic rock which forms the core of most continents, the rising material from the upper mantle crystallized to form basaltic and related denser rock. Since the lithosphere of the Earth is floating on denser, more plastic deeper layers, this newly created basaltic rock initially equilibrated at a level lower than the lighter granitic continents nearby. The result was a depression, the Atlantic Ocean, situated between the separating continental masses. This depression was filled by the invading waters of the Tethys Sea (now Mediterranean) and Pacific Ocean which existed at that time.

Although the young Atlantic floor was lower than the adjacent continents, it still retained a great deal of its original heat, particularly adjacent to its site of formation at the spreading rift. As the new lithosphere was rafted outward from the rift, it slowly cooled and contracted. The youngest or most recently crystallized crust was swollen with heat, producing a melt in the form of a mountain range situated above the site of upwelling and rifting. As separation continued, the older crust was transported laterally farther and farther away from its original site of formation. In time it cooled and contracted, sinking to greater depths to form the deep ocean floor located between

the continents and the younger mountain range in the center of the ocean.

The process of separation in the Atlantic has been occurring at a relatively continuous rate for the intervening 200 million years. The central mountain range of freshly forming oceanic lithosphere of today is the Mid-Atlantic Ridge. Parallel to the crest of this mountain range and at its center is a deep rift valley, caused by the pulling away of two large lithospheric plates: the North American plate which is moving west and the African plate which is moving east. The floor of this rift valley is mantled with very young basaltic lava flows which are fed from the upwelling hot mantle material below.

As each episode of rifting or sea-floor spreading occurs, a portion of the plastic upper mantle material rises, and because of reduced confining pressure, undergoes partial melting. The partial melt rises towards the surface where it is probably stored temporarily in a shallow chamber. Finally a portion of this magma eventually flows out onto the sea floor as basaltic lava flows at a temperature of approximately 1250°C. When this hot lava comes into contact with the cold seawater of the ocean floor, it is quickly cooled into a tangled mass of lobate flow tongues about the size and shape of pillows. Such "pillow lava" forms thicker master flow units which are commonly stacked on one another and build small, steep-sided volcanoes.

Immediately after formation this volcanic terrain is subjected to contractional coddling and the local tensional forces of sea-floor spreading. The newly formed crust is cracked and faulted as it is transported laterally to make room for the next intrusive and volcanic cycle.

Such faulted volcanic terrain is the bedrock which underlies most of the world oceans. It represents the most common form of volcanic products on earth but until recently was unavailable for systematic study. In 1972 a comprehensive marine field program called Project *Famous* (French-American Mid-Ocean Undersea Study) was initiated to investigate the volcanic and tectonic processes taking place in the inner rift valley of the Mid-Atlantic Ridge. During the course of this four-year program, a unique series of bottom photographs were obtained. These photographs portray the original volcanic features as well as their subsequent modification by tectonic processes. Many of the photographs were obtained firsthand by scientists of the rift valley floor in small deep diving submersibles. The remainder were taken using surface-lowered remote camera units. Documentation and interpretation of observations, photographs, and samples

have been published in a variety of journals. The purpose of this photographic atlas, however, is to present a visual aspect of the terrain and geological features occurring in the rift valley. Photographs of the various types of features are grouped together so as to emphasize the similarity or modification of important forms and structures. It should be pointed out that the principal emphasis of this atlas is on the oceanic crust exposed within the rift valley. For that reason, little mention is given to the abundant marine life observed on areas where the sediment cover was thick enough to bury the bedrock surface.

In press: *Geological Society of America*.

Supported by: NSF Grant OCE 73-09736 and NOAA Grant 04-3-185-17.

LATE ORDOVICIAN PERALKALINE GRANITES FROM THE GULF OF MAINE

O. Donald Hermes and Robert D. Ballard

Fourteen outcrops of bedrock in the Gulf of Maine were collected using the submersible, *Alvin*. One station yielded a fine-grained felsic pyroclastic rock, two stations calcalkaline granites, and the remaining eleven sites exposed peralkaline granites. The peralkaline granites range from hypersolvus to subsolvus varieties and exhibit slightly different textures and mineralogical features that reflect minor differences in their local crystallization and subsolidus histories. However, similar chemistry and zircon ages, that yield a slightly discordant 400-450 m.y. U-Pb age, indicate that all of the peralkaline granites from the Gulf are genetically related. Based on similar mineralogy, texture, rock chemistry, and primary radiometric ages, these granites are interpreted to have been intruded during the same igneous episode as the subaerial alkaline granites of eastern Massachusetts.

The Gulf of Maine lies within the Avalon Platform Province. The local occurrences of late Ordovician - early Silurian alkaline granites may indicate an igneous - tectonic episode that accompanied epeirogenic doming following the major compressional phase of the Taconic Orogeny, but before renewed plate convergence and the final phases of Acadian plate collision during the Devonian and throughout much of the rest of the Paleozoic.

In press: *Geol. Soc. Amer. Bull.*

Supported by: NSF Grants GA-32454 and GD-32558.

OASES OF LIFE IN THE COLD ABYSS

John B. Corliss and Robert D. Ballard

Shimmering water streams up past giant tube worms, never before seen by man. A crab scuttles over lava encrusted with limpets, while a pink fish basks in the warmth.

Inside the research submersible *Alvin* we watch in amazement. We have dived a mile and a half (2.5 kilometers) into the near-freezing depths of the Pacific, yet our temperature probe now registers 63°F (17°C) as we hover over an incredible community living around a warm sea-floor spring.

Our group has come as geochemists and geologists to the Galapagos Rift west of Ecuador to investigate for the first time active hydrothermal vents in the deep sea. While gaining invaluable basic data for understanding earth processes, we also make history for marine biology. The unknown creatures and dense communities of life we have discovered living at these vents, like lush oases in a sunless desert, are a phenomenon totally new to science.

Published in: *National Geographic Magazine*, Oct. 1977.

Supported by: NSF Grant OCE 76-00389.

NOTES ON A MAJOR OCEANOGRAPHIC FIND

Robert D. Ballard

The research vessel *Knorr* of the Woods Hole Oceanographic Institution steamed out of the Panama Canal Feb. 8, 1977, headed for the Galapagos Rift in the Pacific Ocean some 330 kilometers northeast of the Galapagos Islands and 640 kilometers west of Ecuador. The vessel was on a mission to make a detailed study of several hot water vents on the ocean floor in depths of between 2,500 and 2,700 meters. The voyage marked the third major expedition in the last four years to spreading centers where molten lava from the earth's mantle periodically erupts and pushes adjacent crust aside.

Published in: *Oceanis*, Summer Vol. 20(3), 1977.

STATION LOCATIONS FOR Atlantis II-73, Atlantis II-77, AND Knorr-42 CRUISES AND Alvin DIVE TRACKS IN THE Famous AREA

James R. Heirtzler and Helen C. Hays

Lists and positions of stations on cruises *Atlantis II-73*, *Atlantis II-77*, *Knorr-42* and *Alvin* dives on the Mid-Atlantic Ridge during Project *Famous* are given. Station lists include those for camera, water temperature, rock drill, dredges, heat flow and coring. The location of these stations is shown on 12 charts.

Published by: W.H.O.I.

Supported by: NSF Grants OCE 73-09736 A03, DES 74-01543 and DES 73-06421; and NOAA Grant 04-3-158-17.

ARGO MERCHANT
A SCIENTIFIC COMMUNITY'S RESPONSE

John D. Milliman

On December 15, 1976, the *Argo Merchant*, a Liberian tanker, carrying nearly 8 million gallons of number 6 fuel oil went aground at Fishing Rip Shoals 25 miles southeast of Nantucket Island. The ship soon broke in half sending its contents into the sea. Woods Hole scientists, together with the U.S. Coast Guard and National Oceanic and Atmospheric Administration quickly gathered together, outfitted a Woods Hole Oceanographic Institution vessel (*Oceanis*) with the proper equipment to measure background data relevant to potential impact of oil upon the environment. During the cruise a total of 11 stations were occupied and more than 100 samples of suspended particulate, suspended and benthic hydrocarbons and benthic organisms gathered. Luckily, winter winds carried the oil offshore, thereby minimizing the disaster. This emergency taught us, however, we need to have background data on the waters closest to human activity. Moreover, we need to know more about the settling of various types of oil in water, the extent to which oil volatilizes and oxidizes before reaching the bottom, and how can we sample in an impacted area without fouling our ship or sampling equipment. With increased funding and research such data may be available before another disaster such as the *Argo Merchant*.

Published in: *Oceanus* Vol. 20(4), Fall 1977.

Supported by: U.S. Geological Survey Contract 15615.

STRUCTURE AND STRATIGRAPHY OF DIVERGENT CONTINENTAL MARGINS

Kenneth O. Emery

Existing geological and geophysical information shows that the physiographic components of continental margins (continental shelves, continental slopes, and continental rises) in different regions have characteristics that depend upon their tectonic and sedimentary histories. These characteristics also determine whether significant oil and gas accumulations probably are present, may be present, or probably are absent. Most promising are the oil and gas prospects of divergent continental margins whose sediment accumulations are large and less disturbed than those of convergent margins; translation margins are intermediate. Better know-

ledge of all continental margins, particularly in their middle parts, awaits exploration by deep drilling. Without such information estimates of the Earth's total oil and gas resources must remain very incomplete.

In press: *a book*.

Supported by: *Henry Bryant Bigelow Oceanographer Chair*.

*THE 1974 Alvin DIVES ON CORNER RISE AND
NEW ENGLAND SEAMOUNTS
(A technical report)*

James R. Heirtzler, Patrick T. Taylor,
Robert D. Ballard and Robert L. Houghton

During the summer of 1974 an *Alvin* dive was made on Corner Rise, and Nashville, Gil-

liss, Rehoboth, Manning, Balanus and Mytilus Seamounts. The principal characteristics of the topography, sediments and rocks were observed and recorded.

Published by: *W.H.O.I.*

Prepared for: *ONR Contract N00014-74C-0262;
NR 083-004 and NOAA Contract 4-35366.*

G E O P H Y S I C S

THE VECTOR PROCESSOR

Charles R. Denham

VECTOR is a Fortran FUNCTION processor for manipulating three-dimensional vector information by commands which closely resemble the nested notation of vector algebra, without the need for bookkeeping/administrative coding by the user. The computations are performed and stored in an invisible working area which is automatically managed completely free from within. The internal coordinate system is strictly Cartesian for programming simplicity, with conversation in other conventions being made possible by automatic coordinate conversions during input-output operations. The processor includes numerous elementary and advanced vector operations.

Published by: *W.H.O.I.*

Supported by: *MIT-WHOI Joint Program in Oceanography*.

PATSY: A TIME-SERIES PROCESSOR

Charles R. Denham

PATSY is a Fortran Function for manipulating time-series information by simple nested commands which closely resemble algebraic notation. The user is relieved of bookkeeping responsibilities because the time-series calculations and communications are conducted through an internally managed working area which is hidden from the user. Real-, imaginary-, and complex-valued time series of arbitrary length may be used, and a large variety of elementary and advanced time series operations are available. For the sake of simplicity and versatility, the processor operations are conducted strictly

in complex notation, while conversions to- and from-complex form are accomplished automatically through descriptive input/output commands. PATSY has been used successfully to teach the elements of waveform analysis to graduate students whose programming skills ranged from negligible to extensive.

Published by: *W.H.O.I.*

Supported by: *MIT-WHOI Joint Program for Oceanography*.

*A COMPLETE NAVIGATION AND TOTAL GEOMAGNETIC
FIELD PROCESSING PACKAGE USING THE
HEWLETT PACKARD 9830 CALCULATOR*

Robert C. Groman and Hartley Hoskins

A complete data processing package for navigation and total geomagnetic field anomaly is described for the Hewlett Packard 9830 calculator. These programs were designed, written and used during a two-week site survey funded through the international Program of Ocean Drilling (IPOD). These programs permit 1) entry of navigation and total field geomagnetics data; 2) data reduction of total field to magnetic anomaly; 3) data editing, and 4) data display in the form of annotated ship's track and profiled data along the ship's track.

Published by: *W.H.O.I.*

Supported by: *ONR Contract N00014-74C-0262;
NR 083-004 and IPOD Contract CU-WHOI-25903.*

*ABYSSAL SEDIMENT WAVES IN THE
AMIRANTE PASSAGE, WESTERN INDIAN OCEAN*

David A. Johnson and Elizabeth T. Bunce

The deep western boundary current (DWBC) of the Indian Ocean flows northward along the western margin of the Mascarene Basin, and is funneled through a narrow passage (near 09°S, 52°E) prior to entering the Somali Basin to the north. Recently completed geological and geophysical operations within this passage reveal the presence of fields of well-developed abyssal sediment waves, with amplitudes of 10 to 50 meters and wavelengths of hundreds of meters to ~1 km. The two principal fields of sediment waves are confined to the flanks of the passages, and are restricted to a narrow depth interval (~3950 to 4150 meters). Individual waves appear to be elongated parallel to the passage axis and the presumed flow direction of the DWBC. The waves are relatively transparent to low-frequency echo sounding (3.5 kHz) and seismic profiling (17-70 Hz), although weak internal reflectors are present within individual waves. These reflectors are conformable with the overlying sea floor, thereby suggesting neither upslope nor downslope migration of the waves.

Interpretations of the origin of the sediment waves in terms of the local flow regime will require (1) a more precise description of the physiography and structure of individual sediment waves; and (2) closely-spaced measurements of the near-bottom velocity structure of the DWBC within regions of the passage where sediment waves apparently forming.

Published by: *W.H.O.I.*

Supported by: *NSF Grant OCE 76-21522.*

*THE MARINE GEOPHYSICAL DATA EXCHANGE FORMAT -
'MGD77' (BATHYMETRY, MAGNETICS, AND GRAVITY)*

Robert Groman
(representing Woods Hole Oceanographic Institution at the Boulder, Colorado meeting)

Since June 1972, the marine geophysical community has used data exchange formats designed and recommended by an ad hoc working group for the Ocean Science Committee (of the National Academy of Sciences/National Research Council). These formats have been successfully used and have contributed substantially to improvements in data exchange and data management practices. During the use of these exchange formats, deficiencies primarily relating to lack of sufficient detail and documentation have been identified. Informal discussions with many users in industry, government (both national and international), and academia prompted the National Geophysical and Solar-Terrestrial Data Center to host a workshop with a repre-

sentative group of marine geophysical data contributors and users. The "Workshop for Marine Geophysical Data Formats" was held in Boulder, Colorado, on January 18-20, 1977. Twenty-four participants attended the workshop, and from these, six were selected to be members of a task group which would formalize the results of the meeting.

*THE MID-ATLANTIC RIDGE AT 23°N:
BATHYMETRY AND MAGNETICS*

Graham M. Purdy, Philip D. Rabinowitz and
Hans Schouten

We present a compilation of all available bathymetry data in the area around drill sites 395 and 396. Four long east-west magnetic profiles crossing both drilling sites are used to date the crust on which Holes 395 and 396 were actually drilled. Site 395 is located on anomaly 4' west of the Mid-Atlantic Ridge and Site 396 on anomaly 5 east of the Ridge.

The two site surveys (Site 5, Drill Site 395, and Site 6, Drill Site 396) provide dense data coverage over two approximate one-degree squares on the flanks of the Mid-Atlantic Ridge at 23°N. This paper and the accompanying map attempts to place these detailed surveys in their regional context. We will discuss the compilation of bathymetry data and present inversions of four magnetic profiles which detail the spreading history in this region since anomaly 5 time (~10 mybp).

In press: *Init.Repts. Deep Sea Drilling
Project - Leg 45.*

Supported by: *NSF Grant OCE 76-02254.*

*A SEISMIC REFRACTION EXPERIMENT
IN THE CENTRAL BANDA SEA*

Graham M. Purdy and Robert S. Detrick

A seismic refraction experiment in the central Banda Sea is interpreted using both slope-intercept and delay time function methods. The crustal structure is shown to be oceanic with velocities (4.97, 6.47, 7.18, and 7.97 kms/sec) typical of oceanic layers 2B, 3A, 3B and mantle. Individual layer thicknesses vary systematically along the line, though the range of thicknesses observed for layers 2B (1.5 - 2.0 km) and 3A (2.0 - 3.5 km) fall well within the range observed for normal oceanic crust. Layer 3B is unusually thick (2.5 to 4.6 km) resulting in slightly greater than normal depths to Moho of 9-10 km below the sea floor. Shear head waves from layers 3A and 3B are identified on two receivers. In both cases shear wave conversion occurred at the sediment/layer 2 interface. The observed shear wave velocities and intercepts indicate

Poisson's ratio of 0.25 - 0.28 in layer 3 and ~ 0.33 in layer 2. These and earlier results from the southern Banda basin indicate that the entire Banda Sea is underlain by oceanic-type crust.

In press: *J. Geophys. Res.*

Supported by: NSF Grant OCE 75-19150.

*SEDIMENT DISTRIBUTION AROUND
THE BOUVET TRIPLE JUNCTION*

Graham M. Purdy and David C. Twichell

Some features of the sediment distribution pattern and the seismic reflection profiles around the Bouvet triple junction in the South Atlantic Ocean may be most simply accounted for by bottom currents flowing north-eastward through the Bouvet fracture zone.

In press: *Marine Geol. Letter Section.*

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

*SEISMIC REFLECTION PROFILES
ACROSS BLAKE ESCARPMENT*

Robert E. Sheridan, Charles C. Windisch,
John I. Ewing and Paul L. Stoffa

Recently obtained high energy multichannel seismic reflection profiles across the Blake Escarpment show that the oceanic basement, identified as a hyperbolic reflector, forms a deep (>9.0 sec of reflection time) sediment-filled trough at the base of the escarpment. The western boundary of the trough is formed by a steep rise (45° - 60°) of acoustic basement producing an apparent structural relief of more than 2.5 sec for the trough. Seismic velocities were determined on 3.23 to 3.95 km/sec and indicate 4.03 to 4.94 km of sediments in the trough. The steep west side suggests fault control and deposition in a fault-bounded half-graben trough. Undisturbed sediments lie over Horizon β which passes across the trough without deflection on one profile, and which is the shallowest disturbed and upturned reflector on another profile.

Correlation of reflectors involved in the structure of the trough with the nearby DSDP Site 391 indicates that the deeper seismic layers include sediments older than Late Jurassic. These old sediments filling the fault-bounded trough at the base of the Blake Escarpment should include facies deposited during the earliest opening of the Atlantic in perhaps the Early Jurassic.

The seismic reflection profiles also show reflectors at the edge of the Blake Plateau which can be correlated with DSDP drill Site 390. Important reflectors of

basal Eocene, Campanian/Albian and Barremian age can be traced westward to depths of 2.8 sec (3.4 km) under the Blake Plateau. Hyperbolic reflectors, not associated with igneous basement, occurring over acoustically opaque zones are interpreted to be well cemented, high velocity carbonate bank margin complexes as drilled at DSDP Site 392.

Supported by: Lamont-Doherty Geological Observatory.

*GAS-HYDRATE HORISONS DETECTED IN SEISMIC-
PROFILER DATA FROM THE WESTERN NORTH ATLANTIC*

Brian E. Tucholke, George M. Bryan
and John I. Ewing

Reflecting horizons which have anomalously high amplitude and which are conformable to the seafloor at about 500 to 600 m subbottom have been reported in two locations off the United States east coast - one along the crest of the Blake Outer Ridge, and another beneath the upper continental rise off New Jersey and Delaware. Detailed mapping of these horizons shows that (1) the horizon cut across bedding planes in the sediment; (2) subbottom depth of the horizons increases with increasing seafloor depth and thus with decreasing seafloor (bottom water) temperature, and (3) the horizons are restricted to areas where sediment strata dip landward, such anomalous horizons are uncommon within the normal seaward-dipping continental-rise strata.

Deep-sea drilling into or close to the anomalous horizon on the Blake Outer Ridge (Sites 102, 103, 104) recovered methane-rich sediment. Pressure/temperature conditions within the sediment column in both areas of anomalous horizons are appropriate for formation of gas hydrates to several hundred meters depth, thus suggesting that a zone of gas hydrates overlies the anomalous horizons. A plot of the hydrate/gas phase transformation of the methane/seawater system in the sedimentary column, using geologically reasonable values for seafloor temperature and for thermal gradient and sound-velocity in the sediment, shows a good correlation between the depth of the phase change and the minimum depth of the anomalous reflecting horizons. The horizons therefore are thought to represent an impedance contrast caused by the downward change from gas hydrate to gas in the sediment. Landward-dipping strata and the gas-hydrate layers in the areas exhibiting anomalous horizons appear to form traps for free gas, whereby the gas-hydrate layer blocks seaward gas migration and the dipping strata restrict landward migration.

Published in: *Amer. Assoc. of Petroleum Geologists Bull.* 61(5), 1977.

Supported by: Lamont-Doherty Geol. Observatory.

*STRUCTURE OF FALKLAND PLATEAU AND OFFSHORE
TIERRA DEL FUEGO, ARGENTINA*

William J. Ludwig, Charles C. Windisch,
Robert E. Houtz and John I. Ewing

Velocity solutions from 165 airgun-sonobuoy reflection/refraction stations on the continental margin of southernmost South America are presented in 10 seismic structure sections. Also included are an isopach map of Cretaceous and Tertiary sediments (seismic velocities generally less than 4.2 km/sec) in the Magellan, Malvinas, Falkland plateau and Falkland trough basins, and three north-south single-channel seismic reflection traverses of the Falkland plateau, Falkland trough, and North Scotia ridge. The Falkland trough is a sliver of ocean crust between the Falkland plateau and the North Scotia ridge. The acoustic basement and deep sedimentary layers of the plateau extend beneath the trough and then are subducted beneath the northern flank of the ridge. Movement of the ridge and the plateau toward each other has apparently resulted in the deformation and uplift of the overlying sediments to form the northern flank of the ridge.

Supported by: *Lamont-Doherty Geological Observatory.*

*STRUCTURE OF COLORADO BASIN AND
CONTINENT-OCEAN CRUST BOUNDARY OFF BAHIA BLANCA,
ARGENTINA*

William J. Ludwig, John I. Ewing,
Charles C. Windisch, Alberto G. Lonardi and
Francisco F. Rios

New seismic refraction measurements made with radio-sonobuoys, ocean bottom seismographs, and ship-deployed hydrophones are used to improve the knowledge of structure of the Colorado basin and the nature of the boundary between continental crust and oceanic crust. Included are the tabulated results of 120 airgun-sonobuoy stations on the continental shelf, slope, and rise off Bahia Blanca and a schematic (seismic) structure section of these features. The seismic data and information from boreholes on the shelf are interpreted to show the presence of an outer shelf-slope basement ridge, perhaps capped by a volcanic or reefal complex, that may have barred marine deposition from the Colorado basin until the close of the Cretaceous. The ridge of continental basement rock is located beneath the sediments of the upper continental slope, about 80 km beyond the edge of the shelf, at the boundary between continental and oceanic crust. Closely spaced refraction profiles made parallel to isobaths in the vicinity of the continent-oceanic crust boundary suggest stretching and thinning of lower crustal rock, perhaps accompanied by subsidence of continental basement rock to

form the continental slope. Alternatively, as is suggested by others to explain a coincident belt of magnetic and gravity anomalies in the vicinity of the outer shelf-slope, the basement of the continental slope is elevated material of composition similar to oceanic crust.

Supported by: *Lamont-Doherty Geological Observatory.*

*MINICOMPUTER BASED SYSTEM
FOR MARINE SEISMIC DATA ACQUISITION*

Kenneth E. Prada, Donald E. Koelsch,
Keith von der Heydt and Thomas F. O'Brien

A minicomputer-based system for marine seismic data acquisition has proven to be a versatile tool for low and medium frequency reflection and refraction seismic experiments. Developed as a single channel reflection profiling system in 1971, the system has since expanded to a 12-channel capability with automatic gain ranging and programmed delay. A great deal of versatility results from the use of a minicomputer for system control. Adaptive changes may be made either conversationally with the system or by minor programming changes. A unique feature of the system is the field tape format, channel records that are time demultiplexed and gain normalized. This feature eliminates a costly step in the processing phase and simplifies both acquisition and processing of the complex data.

In press: *Inst. of Electrical and Electronic Engineers.*

Supported by: *NSF Grant IDO 74-04094.*

THE ARGO ABYSSAL PLAIN

James R. Heirtzler, Paul Cameron, Peter J. Cook,
Thomas Powell, Hans A. Roeser, Sutisna Sukardi
and John J. Veevers

Twenty geophysical transects were made in the Argo Abyssal Plain to study the magnetic anomalies, bathymetry and seismic structure. Magnetic anomalies were identified as being the Mesozoic anomalies M-10 to M-25, increasing in age from the Java Trench to the northwest continental shelf of Australia. A new bathymetric map shows that the Argo Abyssal Plain is bounded by the 5600 m contour and reaches a maximum depth of 5730 m against the inshore side of the Exmouth Plateau. Joey Rise was found to limit the Argo Abyssal Plain on the southwest. Continuous seismic profiles, sonobuoy data and seismic data from other cruises permit one to contour the depths to oceanic basement. Numerous diapir-like structures were observed, but their nature and origin is obscure.

In press: *Earth and Planetary Science Letters.*

Supported by: NSF Grant OCE 75-20674.

INTERPOLATION OF TIME-SERIES ON THE UNIT-SPHERE

Charles R. Denham

A rotationally-invariant procedure for interpolating unit-sphere information such as paleomagnetic directional stratigraphy is a prerequisite for time-series analysis of those data by conventional methods which employ evenly-spaced points. The interpolation algorithm described here produces spatially and temporally smooth path-segments between data points on the unit sphere. The curves maintain continuity of both speed and heading through the sequence of points, and they are derived piecewise in simple fashion from local data. A complete numerical example is given, whose result is compared with that of the common linear/great-circle method. The interpolator is then applied to an actual paleomagnetic problem in which the similarity between two irregularly-sampled paleomagnetic records is examined. The Appendix is a sample computer program for the procedure.

In press: *Geophys. J. Roy. Astr. Soc.*

Supported by: NSF Grant EAR 76-13359 and
ONR Contract N00014-74C-0262; NR83-004.

OBLIQUE ANHYSTERETIC REMANENT MAGNETIZATION

Charles R. Denham

Oblique anhysteretic remanent magnetization (OARM) is acquired by the application of a strong decreasing, alternating-field (AF) biased by a weak, steady-field (SF) oriented at some angle to AF. The resulting OARM lies in the AF-SF plane, but it is systematically misaligned with respect to AF. The weakest OARM occurs when SF is transverse to AF, but the ratio with longitudinal ARM varies from specimen to specimen. The apparent coercive force of transverse ARM is slightly lower than the longitudinal counterpart. Oblique ARM can be modeled inexactly by invoking fictitious, independent ARM susceptibilities in the transverse and longitudinal directions, each activated by the corresponding component of SF. However, an adaptation of the Stoner-Wohlfarth (1948) mechanism provides a result which is much more physically satisfying although it too is inexact for the two specimens studied here.

In press: *J. Geophys. Res.*

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

IPOD SITE 6: A SITE SURVEY

Graham M. Purdy, Hans Schouten, John Crowe, Donald L. Barrett, Robin K. H. Falconer, G. B. Udintsev, N. A. Marova, V. M. Litvin, C. M. Valyashko, V. M. Markushevich, and V. V. Zdorovenin

Site 6 is located near anomaly 5, between latitudes 22°N and 23°N, about 140 km east of the median valley of the Mid-Atlantic Ridge and 50 km south of the Kane Fracture Zone. The site survey data were collected within an approximate one degree square by the Woods Hole research vessel *Atlantis 11* and the *Academik Kurchatov* of the U.S.S.R. The suggested drill site was the sediment pond at 22°58'N, 43°31'W: this recommendation was based on bathymetry, airgun seismic reflection and magnetics data.

In press: *Init. Repts. DSDP.*

Supported by: IPOD Contract CU-WHOI-25903.

IPOD SITE 6: SEISMIC REFRACTION RESULTS

Donald L. Barrett and Graham M. Purdy

Seismic refraction experiments were carried out at three locations within the Site 6 survey area. The problems involved with working over such rough topography and repeated instrument difficulties resulted in a data set of poor quality. Our primary aims of detailing the shallow seismic structure beneath the proposed drill site and of determining the regional structure over the survey area were not satisfactorily achieved.

In press: *Init. Repts. D.S.D.P.*

Supported by: IPOD Deep Sea Drilling
Project Contract CU-WHOI-25903.

REFLECTION ENERGETICS OF MARINE SEISMIC PROFILES AND ESTIMATION OF THE ACOUSTIC IMPEDANCE STRUCTURE OF THE SEABED - SOMALI BASIN

Sydney T. Knott, Hartley Hoskins and Elroy O. La Casce, Jr.

Geological interpretation of marine seismic reflection profiles is usefully supplemented by systematically measuring the energy (and its variations) of the reflection events typically observed in low-frequency, normal-incidence profiles. Analyses of the low frequency signals received via a passband of at least an octave (e.g. 30-60 Hz) indicate that the variations in reflection energetics can for the purposes of the experimentalist be ascribed principally to vertical and lateral changes in the acoustic impedance of the seabed. By following a simple multi-layer reflection model, impedances can be estimated from the energetics measure-

ments. Techniques and rationale are given for making these observations of seabed reflectance and deriving impedance estimates.

Reflectance and estimated impedance characteristics of the seabed are compared at three stations in the Somali Basin northwest of Chain Ridge and three southeast of the southwesterly expression of the Ridge, which bounds the Basin to the southeast. One station to the southeast is near Deep Sea Drilling Program site #235, where the impedance structure down through the sediments into basement was determined from cores. Estimated impedance structure at the station is in close agreement with that at the site. Having established this agreement, the impedance structures estimated from the reflectance measurements at the stations within the Basin northwest of the Ridge are compared with the structures at the stations to the southeast.

Although recent sedimentation is similar throughout the region, as evidenced by surficial cores and seafloor reflectivity measurements, and a water depth of about 5100 meters at each station, reflectance measurements and impedance estimates show the sedimentation within the Basin evolved differently than that southeast of the Ridge. Two clearly different impedance structures are evident. Northwest of Chain Ridge estimated impedance increases nearly linearly from about 2×10^6 rayls down through the sediment to about 16 to 18×10^6 rayls in basement. South of the Basin proper, a nearly uniform low impedance of about 4×10^6 rayls is evident throughout the sediment column with sharp increases at, or near basement. Reflectance profiles show that the lateral continuity of material properties within the seabed in the southern area is more uniform than in the northern area. Northwest of the Ridge small scale variations over distances of about 2 km are observed in seafloor reflectivity and in seabed reflectance.

In press: *J. Geophys. Res.*

Supported by: ONR Contract N00014-74C-0262; NR 083-004, W.H.O.I. Ocean Industry Program and NSF Grant IDOE-GX-28193.

PLATE CONVERGENCE AND ACCRETION IN THE TAIWAN-LUZON REGION

Carl Bowin, Richard S. Lu,
Chao-Shing Lee and Hans Schouten

During the Middle and Upper Miocene the northern continuation of the Luzon volcanic arc approached the Asian continental margin through subduction of oceanic crust on its western side. Collision deformation began in Pliocene time since Upper Miocene marine fossils are found in the slate belt of Taiwan. South of Taiwan,

the crust-crust contact between the Philippine and Asia plates occurs at the large negative free-air gravity anomaly over the deformed accretionary wedge of the Manila Trench. The deformed sediment wedge has been uplifted to shallower depths towards Taiwan and is interpreted to form part of the southernmost peninsula of Taiwan. The pattern of gravity anomalies suggests that the Luzon Arc has underthrust the Central Mountain Range of Taiwan to at least 40 km west of the Longitudinal Valley. Thus the west edge of the Philippine plate at Taiwan appears to be chisel-shaped in cross section. Recent trans-current faulting along the Longitudinal Valley and beneath the crest of the Central Mountain Range is being superimposed upon this collisional suture. The north end of the vertical fault beneath the Central Mountain Range links with the axis of extensional opening that created the Plain of Ilan on the east coast of Taiwan. The Plain of Ilan is a landward extension of the Okinawa Trough and forms the southwestern end of that extensional back arc structure of the Ryukyu Island Arc. The crust-crust contact between the Ryukyu Arc and the Philippine plate occurs at the negative free-air anomaly of the accretionary wedge. To the west this contact abuts the northward end of the Longitudinal Valley fault. We speculate that the Luzon Arc convergence zone in the region of Taiwan has been sealing southward and that concomitantly a new plate boundary has been developing on the east side of Luzon and progressing northward.

A good correlation of magnetic anomalies trending N70°E has been made in the China Basin west of Luzon. These anomalies are interpreted to be associated with the crest of an extinct spreading ridge which formed the deep portion of the China Basin by separating older but shallower crust. Magnetic anomalies in the westernmost Philippine Basin suggest the existence of north-trending anomalies. The consistency of the skewness, the small amplitude factor, and the bathymetric cross sections here with those of the Central Basin Ridge region to the southeast support the view that the Gagua Ridge may be an extinct spreading center and that the adjacent topography was formed by sea-floor spreading processes.

In press: *Amer. Assoc. Petrol. Geol. Bull.*

Supported by: ONR Contract N0004-74C-0262; NR 083-004.

THE ORIGIN OF THE NINETYEAST RIDGE AND
THE NORTHWARD MOTION OF INDIA,
BASED ON DSDP PALEOLATITUDES

John W. Peirce

Paleomagnetic data are presented from the sediments and basalts at DSDP sites 213, 214, 216, and 217 on or near the Ninetyeast Ridge in the eastern Indian Ocean. The paleolatitudes confirm that the ridge is attached to the Indian plate and that both have moved rapidly northwards since the Late Cretaceous. The Indian plate moved northwards with respect to the south pole at an average rate of 14.9 ± 4.5 cm/yr from 70 mybp until about 40 mybp when it slowed to its present rate of $5.2 \pm .8$ cm/yr.

Basal paleolatitudes on the Ninetyeast Ridge indicate that its volcanic source was approximately fixed in latitude near 50°S, supporting the concept that the ridge is the trace of the Kerguelen hotspot on the northward moving Indian plate. The existence of a "mirror ridge" on the Antarctic plate and the very shallow depths of basement formation on the ridge suggest that the Indian/Antarctic spreading center must have remained near the hotspot from 80 to 40 mybp in spite of one-limb spreading rates of up to 12 cm/yr. This is unexpected in view of the apparently small amount of motion of the Antarctic plate during this time. It is suggested that Antarctica was held nearly fixed by the geometry of other plate motions, and therefore the Kerguelen hotspot caused asymmetric accretion of new plate material at the southwestern end of the Ninetyeast Ridge. Evidence of such asymmetry has been reported in the form of an 11° southerly migration or jump of that spreading center.

The Ninetyeast Ridge paleolatitudes are consistent with the Deccan Traps paleomagnetic poles. However, a comparison of the Australian paleomagnetic poles and these data shows a major inconsistency between 50 and 40 mybp. Although the reason for this inconsistency is not known, the error may be in the present estimates of the relative motions between India and Antarctica and between Australia and Antarctica as well as the paleomagnetic data itself. The two data sets compare favorably in both rate and paleolatitude back to 40 mybp. Prior to 50 mybp they compare favorably in rate but the DSDP data imply that India was 13° farther south than the Australian poles indicate.

In press: *Geophysical Journal*

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SEISMIC REFLECTION PROFILING AND
BASEMENT TOPOGRAPHY IN THE SOMALI BASIN:
POSSIBLE FRACTURE ZONES
BETWEEN MADAGASCAR AND AFRICA

Elizabeth T. Bunce and Peter Molnar

Continuous seismic profiling in the western Somali Basin reveals basement topography aligned approximately north-south. We interpret three buried ridges, approximately parallel to the Davie Ridge in the Mozambique Channel, as fracture zones, along which Madagascar moved away from Africa. These data, therefore, support the northern paleopositions of Madagascar suggested by du Toit and Smith and Hallam. The ridges seem to provide an eastern barrier to sedimentation. The basement topography forming these fracture zones has a different origin from that of Chain Ridge.

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A COMPOSITE TRANS-ATLANTIC HEAT-FLOW
PROFILE BETWEEN 20°S AND 35°S

Tien-Chang Lee and Richard P. Von Herzen

Sixty new measurements together with published heat-flow data in the South Atlantic between 20°S and 35°S latitude have been analyzed. Heat flux is greater through the eastern Mid-Atlantic Ridge flank and basin than their counterparts on the west but the standard deviation or spatial variation is greater on the west, contrary to expectation based on sediment thickness. The variance in the data indicates that this asymmetry in mean heat flux is statistically significant at 87% confidence level. A pair of ridge-flank minima appear in the composite trans-Atlantic profile of heat flux versus seafloor age, suggesting hydrothermal circulation in the young oceanic crust. The Walvis Ridge has a mean excess heat flux of 28 mWm^{-2} ($0.7 \text{ } \mu\text{cal/cm}^2\text{sec}$) above the surrounding Cape and Angola Basins, and decreases along the Ridge towards the northeast. Consistent with the apparent asymmetric distribution in the South Atlantic, it is also significantly higher than that of the Rio Grande Rise. We hypothesize that the trend and larger mean heat flux of the Walvis Ridge is best explained by a hot-spot origin, perhaps combined with higher radioactivity in the crust. However, the morphologic and heat-flow differences between the Walvis Ridge and Rio Grande Rise suggest that these features have different geologic histories.

In press: *Earth and Planet. Sci. Lett.*

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DES 75-09631.

PALEONTOLOGY / SEDIMENTOLOGY

BLACK SEA SEDIMENTARY FRAMEWORK

David A. Ross, Peter Stoffers and
Egis S. Trimonis

In this paper we summarize some results from important previous Black Sea sedimentary studies in order to provide background information useful for the interpretation of data from Leg 428 drilling. The information presented is basically derived from *Atlantis II* cruise 49 (Degans and Ross, 1974) by the Woods Hole Oceanographic Institution and from cruises of the research vessels *Akademik S. Vavilov*, *Vityaz* and *Academik Shirshov* of the Institute of Oceanology of Academy of Sciences of the Soviet Union (summarized by Shimkus and Trimonis, 1974). A listing of important literature concerning the biology, geology, chemistry and geophysics of the Black Sea has been compiled by Laking, 1974.

In press: *Init. Repts. DSDP, Leg 42.*

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

SEDIMENTARY PROCESSES ON THE CONTINENTAL SLOPE OF NEW ENGLAND

Joseph C. Macilvaine and David A. Ross

A detailed small-scale geological study of the continental slope off northeastern United States, confirmed that slumping and turbidity currents are active and effective erosional agents. Massive large-scale failure has occurred where the slope steepens from a gradient of 1.5° to 7.6° , producing scarps hundreds of meters in relief. Smaller scale slumps have occurred on other parts of the continental slope. Some of the material removed by slumping is emplaced at the foot of the continental slope as relatively intact blocks of 1 to more than 100 meters in thickness. Turbidity currents apparently initiated by slumping have eroded V-shaped gullies on the lower portions of the slope.

Bottom current activity is most influential at the shelf break, where it has sorted bottom sediments and resuspended fine material. Laboratory flume experiments and direct observations of the bottom, (using *Alvin* and *Alcoa Seaprobe*) indicate that the sediments on much of the continental slope are not normally affected by bottom currents.

Biological activity can cause both roughening and smoothing of the sediment surface. Tracks made on the bottom by organisms can produce small-scale roughness, of which the larger features will be reduced by reworking by currents. Biological production of fibrous structures, however, may help make the

sediment surface resistant to erosion by bottom currents.

In press: *J. Sedimentary Petrology.*

Supported by: ONR Contract N00014-66C-0241; NR 083-004.

FINE-GRAINED SEDIMENT AND INDUSTRIAL WASTE DISTRIBUTION AND DISPERSAL IN NEW BEDFORD HARBOR AND WESTERN BUZZARDS BAY, MASSACHUSETTS

Colin P. Summerhayes, Jeffrey P. Ellis,
Peter Stoffers, Scott R. Briggs
and Michael G. Fitzgerald

New Bedford Harbor and its approaches form the estuary of the Acushnet River in southeastern Massachusetts. The estuary is weakly stratified and only partially mixed because river discharge is very small. It appears to be typical of the inlets of the coast of New England, and is a branch of a larger estuary - Buzzards Bay.

Silt and clay are being transported into the estuary in suspension by landward-moving bottom currents that are driven by wave and tidal energy. These fine sediments come from Buzzards Bay, but may originate out on the continental shelf. Before the entrance to the harbor was almost completely blocked by a hurricane barrier, these sediments were accumulating in the harbor at rates of about 1-2 cm/yr in the deeps, and less than 0.5 cm/yr in the shallows. Construction of the barrier reduced the efficiency of tidal flushing, causing the rate of siltation to increase by a factor of 4-5. Outside the harbor, silt and clay accumulate in the drowned valley of the Acushnet and in related depressions at rates of 2-3 mm/yr.

In the water column, silt and clay-sized minerals are suspended together in organically bonded agglomerates. During sediment transport, the silt and clay become partially fractionated, probably by differential settling of the agglomerates. Because fractionation is more effective where wave and tidal energy are strongest, there is a smaller proportion of clay relative to silt in the harbor than there is seaward. Nevertheless, the net transport of clay is still landward.

Fractionation due to differential settling also appears to have formed a very thin, soupy layer of clay-rich material at the sediment-water interface, that appears to carpet the study area. This layer seems to form a transition zone between the much more silty and less mobile subsurface sediments and the highly mobile suspensates of turbid near-bottom waters. Further study is needed to ascertain precisely the nature and persistence of this layer.

Wastes rich in metal are discharged into the waters at the head of the harbor, and rapidly become fixed in the bottom sediment throughout the harbor. Together, Cu+Cr+Zn, the three main contaminant metals, locally form more than one percent of the dry weight of harbor sediments. The metals are located in the very fine silt and clay fractions of the sediment. They migrate slowly out of the harbor, most probably by eddy diffusion in near-bottom waters and appear to have spread out over portions of Buzzards Bay in a carpet 10-20 cm thick. Calculations suggest that about 25 percent of the excess metal in the bay is derived by fallout from urban air that blankets the entire country. The remaining excess metal may represent 24 percent of what was discharged into the harbor and shows to what extent the harbor acts as a leaky sink for contaminants.

Organic wastes derived by discharge of sewage are deposited in the harbor, and close to the Clarks Point sewer outfall. Wastes appear to move away from these depocenters in small amounts, under the influence of waves and tides. Organic waste material forms a significant part of the soupy, clay-rich layer that carpets the area. Assuming that organic waste is moved about in the same way that metal wastes are, then perhaps 24 percent of the organic particulates associated with sewage discharge end up in Buzzards Bay.

Clearly, New Bedford Harbor operates as a sediment trap. But it forms a somewhat inefficient trap for clay-sized particles and, as a result, acts as a "leaky sink" for organic and industrial contaminants (here we refer only to contaminants that move as part of the bottom sediment, not to those that remain in solution in the water column). Other estuaries along the coast of New England can be expected to operate in similar ways with respect to siltation and waste dispersal.

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04-6-158-44016 and 04-6-158-44106.

GRAIN SIZE IN LAMINAE OF BEACH SAND

Kenneth O. Emery

Use of a small corer having a piston controlled by a screw-in drive shaft permits the collection of a series of thin (1.67 mm) slices of sand deposits. Several slices are required to penetrate a single coarse- or fine-grained lamina on foreshores of beaches. Grain-size analysis of the sand in each slice by settling tube was followed by computation of statistical parameters using Inman's simple graphic method. The results show that the slices have a much broader range of median diameter, are better sorted, and are more positively skewed

than are those for a composite core of the same sands. This means that investigations of beach-sand sources and of hydraulic conditions of erosion and deposition based upon sand texture are better served by analysis of laminae than of total sample, especially when the latter is collected as a mere handful of sand as it usually is.

In press: *J.Sed.Petrology*, Dec. 1977.

Supported by: Henry Bryant Bigelow
Oceanographer Chair.

DISSOLUTION RATES OF CALCIUM CARBONATE IN THE DEEP OCEAN (I): AN *in situ* EXPERIMENT IN THE NORTH ATLANTIC OCEAN

Susumu Honjo and Jonathan Erez

An *in situ* Water Circulator (ISWAC) was developed and used to measure dissolution rates for a variety of CaCO_3 particles in the deep ocean. Three ISWAC systems were deployed for 79 days at 3600 m, 4800 m and 5518 m on a moored wire in the central North Atlantic ($32^\circ 22.0' \text{N}; 55^\circ 00.8' \text{W}$). Percent weight loss of the particles was measured and specific dissolution rates based on BET surface area determinations were calculated. Rates of dissolution were at least 2.5 to 7.5 higher than in earlier *in situ* experiments in the Atlantic and the Pacific Oceans. Large differences in weight loss were observed between different types of particles. Reagent calcite dissolve much faster than planktonic foraminifera and coccoliths are most dissolution resistant. The differences in specific dissolution rates of these particles were even larger (more than two orders of magnitude). It is concluded that the BET method does not measure the reactive surface area of biogenic carbonates. We suggest that biogenic carbonates have protective coatings that retard their dissolution. These coatings are partially removed by bleaching with NaOCl .

Our results confirm earlier reports on the existence of a CaCO_3 lysocline in the ocean and support a kinetic origin for this lysocline.

In press: *Earth and Planet.Sci.Lett.*

Supported by: NSF Grant OCE 76-02122.

SEDIMENTATION IN SUBMARINE CANYONS, FANS AND TRENCHES

Kenneth O. Emery

The morphology, origins, and practical uses of submarine canyons, fans, and trench sedimentation is traced from their earliest studies to the present and future as an introduction to discussions in 25 chapters

written by many authors.

In press: *Book: Sed. in Sub. Canyons, etc.*

Supported by: Henry Bryant Bigelow
Oceanographer Chair

*SEDIMENTATION OF MATERIALS IN THE
SARGASSO SEA AT A 5, 367 m DEEP STATION*

Susumu honjo

A sediment trap array was deployed in the Southern Sohm abyssal plain, Sargasso Sea, for 75 days beginning on October 20, 1976. The results of an investigation of the sediment collected at 5,363 m (114 m above the bottom) are reported in this paper. The sediment trap consisted of two separate cones with hydrodynamically designed honeycomb collectors with a total collecting area of 3 m². The trap collected 10.35 g of sediment. The estimated flux was 46.0 mg/m²/day. Large particles were rare except for a *Sargassum* fragment and a number of large pteropod shells. Approximately 10% of the sediment particles were larger than 62 µm. Most of the particles were skeletal remains of plankton and clay. A small quantity of anthropogenic material was collected. Carbonate flux was approximately 18% of the total flux and consisted of 93% calcite and 7% aragonite. The flux of coccoliths was about twice (or two times) that of foraminifera. The organic carbon flux was approximately 3% of the total flux and represented approximately 0.5% of the total carbon production in this area. Pigmented particles contained in one type of fecal pellets appeared to be a major source of organic carbon transported to this depth. Fine particles such as clay and coccoliths were also transported directly from the surface layer by these fecal pellets. There was another type of fecal pellet which consisted mostly of clay and contained far less organic matter than the other kind. These clay-rich, organic-poor fecal pellets are probably the result of coprophagy by the zooplankton living in the deep water column.

In press: *J. Marine Res.*

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

*MORPHOLOGY AND STRUCTURE OF THE UPPER
CONTINENTAL MARGIN OFF SOUTHERN BRAZIL*

John D. Milliman

The shelf and upper slope off southern Brazil are underlain by two broad sedimentary basins, the Santos Basin in the north and the Pelotas Basin in the south. The landward edge of maximum sediment thickness in the basins is delineated by a mid-shelf system, the Grande-Santos Fault, which apparently formed

during, or subsequent to, early rifting of the South Atlantic. Both basins also appear to be divided into several north-south sections by the intersection of E-W fracture zones.

Although depth to basement in both basins exceeds 7 km, the lower portion of basin fill consists of Cretaceous lava (Serra Geral). In addition, the Santos Basin contains Aptian salt overlying the Serra Geral. Thus, total post-Aptian terrigenous accumulation in the Santos Basin is generally less than 4 km, mostly derived from erosion of the adjacent Serra do Mar; at least some of the Pelotas sediments were transported northwards from the Rio de La Plata. Unconsolidated sediment, assumed to be post-Miocene in age, is markedly thinner in the Santos Basin than the Pelotas Basin, possibly the result of continued retreat of the Serra do Mar.

Shallow seismic profiling shows that the upper strata in the Santos Basin accumulated as several cycles of foreset beds, the greatest thickness occurring in the northern part of the basin. Comparison with available drilling and eustatic data suggest that these strata deposited in the mid-Tertiary, prograding over an Eocene unconformity. In contrast, sediments in the Pelotas Basin show no sign of foreset deposition, but rather suggest accumulation in near-shore environments, notably lagoons and estuaries, similar to the coastal environments seen along the present-day shoreline. Uplift in the Pelotas Basin may have occurred as recently as the late Tertiary-early Quaternary (as inferred from seismic profiles over the Patos Arch), followed by extensive erosion and subsequent sedimentation.

In press: *Amer. Assoc. Petrol. Geol. Bull.*

Supported by: NSF Grant IDOE GX-41960.

Gonyaulax tamarensis CYSTS

Donald M. Anderson and David Wall

A study designed to determine whether localized blooms of toxic dinoflagellates in the Cape Cod region of Massachusetts are seeded annually from overwintering benthic cysts, produced the following results. Both *Gonyaulax excavata* (Braarud) Loeblich and Loeblich 1975 and *Gonyaulax tamarensis* Lebour 1925 were identified from different salt ponds. The former species (without a ventral pore) was found in Mill Pond, Orleans, whereas the latter (with a ventral pore) was found in Perch Pond, Falmouth. *G. excavata* and *G. tamarensis* have identical cysts, and each species produces two contrasting types which here are termed pellicle cysts and hypnocysts. The former type is probably asexual (vegetative) and of limited

durability under natural conditions, whereas the latter is more likely a hypnozygote and is the overwintering cyst. Hypnocysts of the two species were collected in sediment samples from Mill Pond and Perch Pond in September 1976 and stored at 5°C until February and March 1977 when they were germinated in the laboratory by incubation at 16°C to produce their corresponding motile stages. These germinations *in vitro* preceded naturally occurring blooms of the two species in their respective ponds by a few weeks. Excystment was stimulated by the temperature increase, but was not appreciably affected by light regime, nutrient concentration or chelator concentration. However, the incidence of motility among the excysted germlings was optimum in highly chelated medium and in the presence of light. This evidence strongly supports the "cyst hypothesis" of toxic bloom initiation without eliminating other possible mechanisms. The wider implications of these results may be that many red tides in New England-eastern Canadian waters are initiated through the displacement of motile estuarine populations into nearshore areas by tidal currents and surface runoff, although the potential existence and importance of offshore cyst reservoirs cannot be discounted.

In press: *J. Phycolgy*.

Supported by: NOAA Contract 04-6-158-44016 and Jewdtt Foundation.

CORRECTED AGE OF THE PLIOCENE/PLEISTOCENE BOUNDARY: END OF A CONTROVERSY

Bilal U. Haq, William A. Berggren
and John A. Van Couvering

Calcareous plankton datum events are referred to the Pliocene/Pleistocene boundary at Le Castella, the stratotype Calabrian at Santa Marie de Catanzaro, and to deep-sea sediments in 6 piston cores. The boundary is correlated by multiple overlapping criteria to a level at, or slightly above the top of the Olduvai Event, giving a revised estimate of about 1.5 Ma for the age of the boundary. The Pliocene/Pleistocene boundary is thus coeval with the earliest of four major climatic deteriorations in the Pleistocene, reconciling paleoclimatic concepts with the chronostratigraphic definition of each epoch.

In press: *Nature*.

Supported by: NSF Grant OCE 78-21274.

*GEOTECHNICAL PROPERTIES OF OCEAN SEDIMENTS
RECOVERED WITH GIANT PISTON CORER:
BLAKE BAHAMA OUTER RIDGE*

Armand J. Silva and Charles D. Hollister

Consolidation tests were conducted on sediment samples from four cores (17-31 meter lengths) obtained with the Giant Piston Corer on the Blake Bahama Outer Ridge (water depths 4758-4962 m). Three of the cores (GPC-7,8,9) had similar composition (calcareous lutites) and texture (60% clay) and similar vertical variability in water content, shear strength and carbonate profiles with very large decreases in water content (average decrease = 52%) occurring in the 20-meter depth. The fourth core (GPC-11) had considerable sand and silt-sized material (calcareous tests) and much higher shear strength. The consolidation results of core GPC-11 showed a significant amount of overconsolidation suggesting that more than 10 meters of sediment has been eroded and that the core was taken in the bottom of a large erosional furrow. Correlations are proposed through use of a mineralogy factor such that the mineralogy of the clay fraction is combined with effects of stress history and clay fraction influence.

Although clay mineralogy does have an effect on consolidation behavior, the effects of consistency coupled with the percentage of calcium carbonate exert the greatest influence on the consolidation characteristics of these sediments.

In press: *Marine Geology*.

Supported by: ONR Contract N00014-66-C-0241; NR 083-004.

*EROSION OF FINE-GRAINED MARINE SEDIMENTS:
SEA-FLOOR AND LABORATORY EXPERIMENTS*

Robert A. Young and John B. Southard

Estimates of threshold erosion velocities have been obtained in the field and in the laboratory for marine mud relatively rich in organic matter and having an active fauna. A sea-floor flume was used to erode undisturbed sediments on the sea floor, while a laboratory flume was used to study the effects of sampling, redeposition, bioturbation, organic matter content, and compaction time on erosion resistance.

Critical shear velocity, u_{*c} , for erosion of muds *in situ* ranged from 0.32-0.84 cm/sec and u_{*c} was apparently independent of season or bulk physical properties. Erosion was often but not always initiated at biogenically disturbed portions of the bed. Lee drifts around small bed roughness elements were the most common constructional bedforms observed during the sea-floor experiments, and narrow and shallow longi-

tudinal furrows were the most commonly observed erosional features. Tidal u_c values measured at the field site were of the same magnitude as the u_c values measured with the sea-floor flume.

Mean u_c for muds redeposited and bioturbated for 1 day to 60 days in the laboratory flume (0.92 cm/sec) was greater by a factor of two than mean u_c for muds eroded *in situ* (0.45 cm/sec). As bioturbation time in the laboratory increased, u_c decreased. Increases in sediment organic content were found to increase u_c systematically in flat, non-bioturbated laboratory beds.

Supported by: ONR Contracts NONR-4029(00) NR 260-101; and N00014-75C-0291; NOAA Contract 04-5-022-7; W.H.O.I. Ocean Industry Program; and a Fellowship from their Education Office.

NILE SUBMARINE FAN: SEDIMENTATION, DEFORMATION, AND OIL POTENTIAL

Colin P. Summerhayes, David A. Ross
and Peter Stoffers

The Nile Submarine Fan is one of the largest in the world. Fan sedimentation probably began in the late Pliocene, burying Miocene carbonates and evaporites (Messinian). Salt flow due to sediment loading caused uplift of the fan's eastern flank to form the salt domed Levant platform. The fan's western flank - the Nile Cone - is deformed by minor folding, faulting, and slumping. The modern fan ends at the Mediterranean Ridge, but formerly extended further, as Nile-derived turbidites are found beneath the ridge. Tectonic and salt-flow deformation of the ridge occurs as a response to subduction of the African plate beneath the European plate.

Piston cores about 10 m long show that carbonate sediment occurs west of the fan and on the Mediterranean Ridge. Channels on the Nile Cone contain thick, clean, well-sorted, coarse-medium sands. Thick sequences of thinly bedded muddy turbidites occur between channels. On the Levant Platform are complex mixtures of thin turbidite sequences and carbonate muds, while young channel deposits are lacking. East of the platform in the Cyprus Basin are mainly grey hemipelagic muds. Thin sapropels (with up to 25% organic matter) are common in cores from all over the area. The turbidites also contain substantial organic matter (up to 2%) mostly as plant fragments.

Sapropels and turbidites form potential petroleum source beds over the entire fan; channel sands form potential petroleum reservoirs that may be most common on the Nile Cone. Up-dip migration of oil to stratigraphic traps

in abandoned channels makes the middle and upper parts (apex) of the Nile Cone of interest as a potential petroleum reserve. Similar traps, as well as structural traps, may occur beneath the Levant Platform.

In press: *Offshore Technology*.

Supported by: NSF Grants DES 74-13212 and OIP 75-02516.

THE ENVIRONMENTAL AND CLIMATIC DISTRIBUTION OF DINOFLAGELLATE CYSTS IN MODERN MARINE SEDIMENTS FROM REGIONS IN THE NORTH AND SOUTH ATLANTIC OCEANS AND ADJACENT SEAS

David Wall, Barrie Dale, George P. Lohmann,
and K. Woollcott Smith

Quantitative treatments of 168 dinoflagellate cyst assemblages from modern marine sediments were used to decipher the salient environmental and climatic features of the distribution of common living cyst-based taxa. Surface sediment samples were studied by routine palynological methods from estuarine, continental shelf, slope and rise zones and abyssal plains between latitudes 62°N and 27°S within fourteen geographic regions of the North and South Atlantic Oceans, the Caribbean and Mediterranean Seas and from one region in the South-eastern Pacific Ocean near Peru, to meet this general objective. The results were expressed as percentages of species present and statistically analyzed by multivariate Q-mode factor analysis, cluster analysis and by calculation of a diversity index, using pre-existing computerized routines.

Inshore to offshore and latitudinal (climatic) variations in distribution were identified and they involved individual taxa, associations of species diversity and specimen densities (cysts per gram of sediment). They were related empirically to changing surface water environments above and this suggested that biologic-ecologic phenomena, which involve species-water type relationships for different taxa, combined with hydrodynamic (current) systems, are the most important factors that control cyst distribution in the bottom thanatoconosis. However, geologic factors such as recycling of older specimens and outcroppings of relict Pleistocene-Early Holocene sediments exert their influence too.

An ecologic classification for extant cyst-based species is proposed in the format of classical "plankton elements". This format is dictated by the existence of dual trends (environmental and climatic) in cyst distribution. It is suggested that genesis of ecologic species-groups of this nature during evolution can be interpreted by or "predicted" from stability-predictability concepts as developed in

contemporary ecologic work, if surface water masses are considered to represent unique hydrographic climates with innate stability and predictability characteristics. This concept of "hydroclimatic stability" is used to identify fossilizable living dinoflagellates as being environmentally adapted to unstable conditions around continental margins and comparable shallow water environments around oceanic islands. In addition there is a tendency for the more stenotopic extant cyst-based taxa to be adaptively specialized towards more stable sectors of nearshore and offshore plankton environments which develop at the terminal and subterminal ends of temperature and salinity regimes or profiles.

One taxonomic change is introduced: *Planinosphaeridium choanum* (Reid 1974) nov. comb. is proposed from the basionym *Ataxiodinium choanum* Reid 1974.

In press: *Marine Micropaleontology*.

Supported by: NSF Grants GB-34106 and GB-12405; and NOAA Contracts 04-6-158-44016 and 04-6-158-44106.

LATE NEOGENE PLANKTONIC FORAMINIFERA
BIOSTRATIGRAPHY OF THE RIO GRANDE RISE
(SOUTH ATLANTIC)

William A. Berggren

Late Neogene planktonic foraminiferal biostratigraphy of eight piston cores atop the Rio Grande Rise (2100-2300 m water depth) reveals the presence of late Pleistocene, and intra-Pliocene, erosional unconformities. These unconformities span an aggregate time interval ranging from 1-12 m.y. The biostratigraphic-biochronologic framework suggests late Neocene (pre-Pleistocene) average sedimentation rates of ca. 0.3 cm/1000 yrs. and a continuous stratigraphic record over the interval 7-3 Ma and 14-12 Ma.

Phylogenetic relationships within the *Globorotalia miozea* and *G. puncticulata-crassaformis* lineages allow a refined 3- and 5-fold zonation of the Late Miocene (11-5 Ma) and Early Pliocene (5-3 Ma), respectively, of the mid-latitude Atlantic. The virtually simultaneous evolutionary appearance of *G. conomiozea* and *G. mediterranea* (from *G. conioidea* and *G. miozea*, respectively) at ca. 6.5 Ma and 6.3 Ma, respectively, and a brief (<0.5 my) overlap in the ranges of *G. margaritae* and *Globoquadrina dehiscens* corroborate recent findings elsewhere. The former events serve to identify the approximate position of the Tortonian/Messinian boundary, the latter to define a new, short zone at the top of the Miocene. The Miocene/Pliocene boundary is recognized in three piston cores and Site 357 on the basis of several multiple reinforcing criteria of re-

gional (*i.al.* LAD of *Globoquadrina dehiscens* and *G. mediterranea*) and local (*i.al.* FAD of *Globorotalia scitula* and *Globigerinoides conglobatus*) significance.

In press: *Marine Macropaleontology*.

Supported by: NSF Grants OCE 76-21274 and OCE 74-01744.

BIOCHRONOLOGY

William A. Berggren and John A. Van Couvering

Biochronology is the organization of geological time according to the irreversible process of evolution in the organic continuum. It is an ordinal framework which measures all but youngest Phanerozoic time with greater resolution (ca. 1 m.y., the average age-range of species in rapidly evolving lineages) if with less accuracy than radiochronology. Both are aspects of geochronology. In contrast, biostratigraphy (strictly speaking) is iterative, consisting of observed (not predicted) superpositional sequences of fossils without inherent chronological significance. (This is to say that an upside-down biostratigraphy or one with huge time-gaps is perfectly useful as long as it is consistent.) It is the arrangement and correlation in time of biostratigraphies that is the often unappreciated role of biochronology. The basis of biochronological correlation is any notable singular occurrence, or "datum event" in the fossil record, which has a geographical range overlapping the spatial limits of coeval but disjunct biostratigraphical zones. Biostratigraphic sequences are, however, the milieu in which datum events in the biochronology of different fossil lineages are compared and radiometrically calibrated. The concept of biochronology is illustrated by reference to the essentially isochronous first appearance datum (FAD) of the planktonic foraminiferal species *Globigerina nepenthes* and the three-toed horse *Hipparion* in the marine and continental stratigraphic record, respectively, during the late Middle Miocene, ca. 12.5 Ma.

In press: *Amer. Assoc. Petrol. Geol. Bull.*

Supported by: NSF Grants DES 74-21983 and OCE 76-21274.

MARINE RESOURCES

POTENTIAL FOR DEEP-OCEAN PETROLEUM

Kenneth O. Emery

Upper continental rises and lower continental slopes are believed to have the best potential of the entire deep-ocean floor for future supplies of petroleum. However, information is based only upon inferences from indirect geophysical and geological data. If drilling supports these inferences, deep-ocean petroleum may considerably augment existing sources. Serious pollution of the ocean is unlikely, because upper rises and lower slopes are remote from shores and areas of intense fishing.

Presented in: *Wallenberg Symposium, Sweden.*Supported by: *Henry Bryant Bigelow Oceanographic Chair.*

MARINE MINERAL RESOURCES AND UNIFORMITARIANISM

Kenneth O. Emery

Fossil fuels and other mineral deposits can be considered examples of the general principles of uniformitarianism, because they have been formed during long geological time by geological processes that are more or less understood. In contrast, man's mining of the deposits has undergone a logarithmic increase in rate since the Industrial Revolution, in keeping also with the logarithmic increase in world population; this is considered an example of catastrophism -- both for the mineral deposits and for mankind. Effects of mineral shortages from the land and ocean floor are being felt both by industrially advanced and underdeveloped countries, but their political remedies are almost diametrically opposite.

Supported by: *W.H.O.I. Ocean Industry Program, and Henry Bryant Bigelow Oceanographer Chair.*

THE SEABED OPTION

Charles D. Hollister

"Where on earth can we permanently isolate toxic radioactive waste that is dangerous to man and his food chain for periods of a million years or more?" This question was first posed to me in 1973 by Dr. William P. Bishop, who was then with Sandia Laboratories, a government research facility at Albuquerque, New Mexico. My initial reaction was a flat "not in our ocean; not in my own backyard". The prospect of a contaminated ocean that might hurt my children or any other human beings turned me against the idea almost completely. But a number of

tantalizing questions persisted. What exactly would be entailed in the disposal of high-level radioactive waste in the ocean? Could the waste material just be dumped into the water? Could it be pushed off the fantail in a canister and allowed to fall to the bottom? Not likely. Probably, it should be buried within the geological formations beneath the sea floor - in some stable, useless, environmentally predictable region, an area that would remain unchanged for the next several million years.

Published in: *Oceanis.*Supported by: *Sandia Laboratories Contract 05-2415.*

MINERAL DEPOSITS OF THE DEEP-OCEAN FLOOR

Kenneth O. Emery and Brian J. Skinner

Deep-ocean mineral deposits are diverse in character and origin. They are the result of geological processes occurring along continental and plate margins, and their extensions on the deep-ocean floor. Copper, lead, and zinc deposits are likely to form along continental margins, and in continental crust, during the earliest stages of plate divergence. Thermal circulation of ocean water, driven by heat from a newly forming margin of divergence, reacts with rocks of the continental crust, leaches metals, and brings the resulting solutions into contact with ocean bottom water. Precipitation of ore minerals can occur by several processes. Subsequently, these early metal deposits become deeply buried under thick sediments of continental rises, which also are nearly restricted to continental margins of divergence. During the later history of plate divergence, when the spreading edge is far removed from continental crust and is flanked only by oceanic crust, copper can be leached from mid-ocean basalts and deposited as poorly crystallized ore material on the ocean floor.

Continental rises and marginal basins (which are concentrated where converging plate margins coincide with continental margins) are the chief potential sites for deep-water oil and gas deposits. Continental margins of translation are poor prospects for economic deposits of either metals or petroleum. No economic placer deposits are likely in any deep-ocean environment, but the chemically precipitated ferro-manganese nodules, with potentially valuable contents of copper, nickel, and cobalt, are widespread and important.

Published in: *Marine Mining, vol.1(1/2), p.1-11, 1977.*Supported by: *Henry Bryant Bigelow Oceanographer Chair.*

INTRODUCTION TO OCEANOGRAPHY

David A. Ross

The field of oceanography has undergone several changes since I wrote the first edition of this book. One of the most important is the growing awareness of marine pollution and how it affects the coastal zone and ocean. Another development is the desire of many countries and industries to turn to the ocean for mineral resources, especially sources of energy such as oil and gas. The past dream of feeding much of the world's population from the sea has been somewhat abandoned, in part replaced by a dream to get more of the world's energy needs from the ocean. Finally, the last few years have witnessed an increasing legal interest in the ocean as the world's nations are claiming more and more of the sea floor. These claims have led to several Law of the Sea Conferences, which so far have failed to satisfactorily resolve the claims. Because of these developments, I have added two new chapters - Marine Pollution and The Law of the Sea - and I have rewritten the chapter on Marine Resources. The other chapters have all been updated to include much of the new scientific information of the last seven years. Over a hundred new figures have been added.

As before, I have attempted to describe and explain oceanography in a manner that is understandable to nonscientists. Since oceanography is the application of all science to the phenomenon of the ocean, I have tried to show the role of the separate scientific disciplines in the study of the ocean, but more important, how they interact. I have also discussed modern marine technology and mentioned some historical aspects of oceanography.

Published: *Book, Introduction to Oceanography (Second Edition).*

THE USE OF THE OCEANS

David A. Ross

The oceans, as most everyone must know, covers about 72 percent of our planet (which is named for the remaining 28 percent). These oceans have fascinated and challenged man for centuries. In the past, man (and woman too, of course) has carefully exploited the ocean, first as a source of food, and later as a means of transportation. Within the last few years, however, the oceans have become important to us because we see them as offering a solution to many of modern man's problems. For example garbage from land is to be dumped into the ocean never to be seen again, fish and other biological resources are to be caught and used to meet the protein deficiency of much of the world's human population. Non-biological marine resources such as oil and gas from the continental shelf and perhaps deeper areas may, in the near future, help solve our energy prob-

lem. Indeed, just the beginning of the implementation of such dreams has already produced severe political, social, and ecological problems associated with the marine environment. Countries are already planning how the oceans can be divided up, so that they will get their "fair share". Economists, politicians, and others are producing almost daily, optimistic or pessimistic views (depending upon your own basic prejudice) about the ocean and its resources. Equally loud reports come from environmentalists, conservationists, government sources, and oil companies concerning the pollution and potential destruction of the ocean. Well, where is the truth - what are the real problems and opportunities associated with the ocean? This book is written in an attempt to shed some light on how we now use the ocean and what we can do in the future. What I am trying to do is present some basic information about the ocean in a form that will be understandable to people who are not oceanographers, but who are interested and concerned about the marine environment.

Supported by: *W.H.O.I. Marine Policy Program.*

TRAINING AND TECHNICAL ASSISTANCE
IN MARINE SCIENCE: A VIABLE TRANSFER PRODUCT

David A. Ross and Leah J. Smith

Marine science is presented as a possible transfer product for training and technical assistance programs with developing countries. To develop this point we present the major research interests, techniques and instruments of the various branches of marine science and show how some could be used in a transfer program. To ascertain past experience and present interest in cooperative projects with foreign scientists we sent a questionnaire to over 100 U.S. marine scientists. The U.S. scientists showed a high level of interest in cooperative marine science programs and over two-thirds had participated in some type of international marine science program, many of which involved marine technical assistance. The respondents suggested many problem areas in such programs, particularly inadequate funding, variations in scientific background among participants, cultural and language problems, and government bureaucracy. The experiences and criticism of some marine scientists from developing countries are also reviewed and compared to the views of U.S. scientists. The foreign scientists noted as problems insufficient opportunity to participate in the planning of the programs, inadequate length of programs, and difficulties with funding and government support. We suggest several mechanisms to expand and improve the effectiveness of educational and technical assistance programs in the marine sciences with developing countries. Based on our study we feel that there is considerable interest among U.S. marine scientists in having training and technical assistance marine science programs with foreign countries. Further developments await funding and leadership.

Supported by: *W.H.O.I. Marine Policy Program.*

*DESCRIPTIONS OF WOODS HOLE OCEANOGRAPHIC
SEDIMENT CORES
Volume 5*

By the Staff
of the Sea Floor Samples Laboratory

Edited by
David A. Johnson and Alan H. Driscoll
(A Technical Report)

This report supplements Volumes 1-4 of the core descriptions published previously in this sequence. It contains visual descriptions and smear slide analyses for all cores received in the geological samples collection of the Woods Hole Oceanographic Institution between November, 1973 and November, 1976. Approximately 368 sample localities from the North Atlantic, Mediterranean, and South Atlantic are represented. Charts of ships' tracks and updated computer listings of all cores in the Woods Hole Oceanographic Institution collection are also included.

OCEAN ENGINEERING

OE-1

DEPARTMENT OF OCEAN ENGINEERING

Earl E. Hays, Department Chairman

ACOUSTICS

*INTENSITY STATISTICS FOR LONG-RANGE
ACOUSTIC PROPAGATION IN THE OCEAN*

George V. Frisk

A statistical analysis of the intensity of acoustic signals received from three sources (9.8, 110, and 262 Hz) towed at long ranges (100-3000 km) in the ocean is presented. The experimental probability density functions for the linear intensity are tested against the following density functions using the Kolmogorov-Smirnov test at the 5% significance level: exponential, Gamma, log-normal and log-normal with a standard deviation of 5.57 db. It is found that no single function adequately represents the experimental density functions at all three frequencies, and none of the functions is appropriate at 262 Hz. At 9.8 Hz, three distributions (Gamma, log-normal, and log-normal with a 5.57 db sigma) theory yields good results. The ability of all the functions to describe the experimental results decreases with increasing frequency.

Supported by: *Naval Electronic System Command.*

*AN ALGORITHM FOR THE NUMERICAL EVALUATION
OF THE HANKEL TRANSFORM*Alan V. Oppenheim, George V. Frisk,
and David R. Martinez

A procedure is proposed for the numerical evaluation of the Hankel (Fourier-Bessel) transform of any integer order using the FFT algorithm. The basis for the procedure is the "projection-slice" theorem associated with the two-dimensional Fourier transform.

Supported by: *Adv. Res. Projects Agency
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*ACOUSTIC DETECTION OF DEMERSAL FISH TO WITHIN
FIFTEEN CENTIMETERS OF THE BOTTOM
IN EIGHTY METERS OF WATER*Marshall H. Orr, Earl E. Hays,
and Frederick R. Hess

Acoustic records are presented which show that demersal fish can be individually detected to within 15 centimeters of the ocean bottom in 80 m of water.

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

*ACOUSTIC MONITORING OF INDUSTRIAL CHEMICAL
WASTE RELEASED AT DEEP WATER DUMP SITE 106*

Marshall H. Orr and Frederick R. Hess

Certain chemical wastes of industrial origin form flocs or particles upon being introduced into sea water. High frequency acoustic backscattering systems have been used to study the process by which the particulate phase of industrial chemical waste is dispersed in a water column (depths > 2000 m) with a sharp seasonal thermocline. The particles have been found to remain trapped for extended periods in the mixed layer, to accumulate on the density structure found between the mixed layer and the seasonal thermocline, to accumulate on the density structure associated with the seasonal thermocline and on occasion, to penetrate the seasonal thermocline and form a diffuse cloud in the main thermocline.

Rhodamine WT dye associated with the effluent phase of the chemical waste has been observed to remain in the same section of the water column as the acoustically detected particles. This indicates that acoustic systems can be used as livetime monitors of industrial chemical waste plumes and guide the sampling of interdisciplinary research groups trying to access the environmental impact of industrial chemical wastes released into the open ocean.

The persistence of the particle phase of the chemical waste in the mixed layer (at least 74 hrs) and their accumulation on the isopycnal structure indicates that those members of the biological community which concentrate in these depth ranges will be exposed to and may assimilate trace metals and other pollutants associated with the wastes.

Supported by: *NOAA Grants 04-6-158-40072 and 7-35181.*

*REMOTE ACOUSTIC MONITORING OF NATURAL
SUSPENSATE DISTRIBUTIONS ACTIVE SUSPENSATE
RESUSPENSION AND SLOPE SHELF WATER INTRUSION*

Marshall H. Orr and Frederick R. Hess

Acoustic data, transmissometer data and calculations are presented which indicate that high frequency acoustic backscattering systems can become a valuable tool in the remote monitoring of suspended particle distributions and active resuspension areas. Data is also presented which shows that acoustic backscattering systems can be used to remotely detect slope shelf water frontal zones. Towed acoustic systems should be able to map the extent of the frontal zone and add significantly to the understanding of frontal zone processes.

Supported by: *NORDA Contract N00014-77-C-0196.*

*LOW-FREQUENCY ACOUSTIC FLUCTUATIONS AND
INTERNAL GRAVITY WAVES IN THE OCEAN*

Robert R. Porter and Robert C. Spindel

Acoustic phase and amplitude fluctuations measured during two experiments, one near Eleuthera Island and one near Bermuda, are presented and interpreted in terms of the interaction of sound with internal gravity waves. Data were collected with a variety of sensors including drifting ship-suspended hydrophones, sonobuoys (free-floating acoustic receivers equipped with a UHF transmitter for data communication), and moored hydrophones. The phase data were corrected for hydrophone motion by means of a bottom-moored Doppler navigation system. Oceanographic data are presented and compared with the acoustic data: these data comparisons show that internal waves are responsible for much of the acoustic fluctuations. Phase spectra obtained with moored hydrophones show a rapid spectral decay at frequencies above the highest observed Brunt-Vaisala frequency as predicted by internal-wave-acoustic models. Spectra obtained with drifting hydrophones are compared with a recently proposed random, multipath model based on interaction of sound with internal waves. Spectra obtained for drifting hydrophones at a depth of 1500 m agree with the multipath-model prediction. Spectra from phones at shallower depths exhibit an order of magnitude at a depth of 300 m produce spectra with a complex frequency dependence that cannot be predicted at the random multipath model.

Supported by: *ONR Contracts N00014-74-C-0262; NR 083-004 and N00014-70-C-0205; NR 083-325.*

*STATISTICS OF LOW FREQUENCY MULTIPATH
FLUCTUATIONS IN THE OCEAN*

Robert P. Porter and Robert C. Spindel

Statistics of fluctuations of low frequency sound in the ocean are analyzed for an arbitrary number of paths. Covariances are derived for the intensity, phase rate (time derivative of the phase) and related parameters. Power spectra are derived from the covariances. The multipath results are based on weakly fluctuating single paths whose phase is perturbed by the internal-wave field. The theory is illustrated by deriving some results for a single internal wave. We specialize to a large number of equal energy paths by appealing to the central limit theorem which states that the Cartesian components for the multipath field are Gaussian distributed. Some results available in the literature are shown to be valid for the special case of a

large number of paths. Power spectra for data obtained in a recent experiment are shown to follow the predictions of this analysis.

Supported by: *ONR Contracts N00014-74-C-0262; NR 083-004 and N00014-77-C-0196.*

ACOUSTIC PHASE TRACKING OF OCEAN MOORINGS

Robert C. Spindel, Robert P. Porter
and John A. Schwoerer

An acoustic tracking technique for monitoring the motion of deep ocean moorings is described. The system uses Doppler phase shifts from bottom-moored beacons to resolve 3-cm motions. The motion of two intermediate depth moorings is presented.

Published in: *Inst. Elec. and Elec. Eng.
(IEEE) J. of Ocean Engineering.*

Supported by: *ONR Contracts N00014-70-C-0205; NR 083-325 and N00014-74-C-0262; NR 083-004.*

A MOBILE COHERENT LOW-FREQUENCY ACOUSTIC RANGE

Robert C. Spindel, Robert P. Porter
and Douglas C. Webb

A portable system for the measurement of certain underwater acoustic propagation phenomena is described. Acoustic sources and receivers of special design are used. A precision tracking system enables coherent signal reception in the presence of source-receiver motion. The major elements of the acoustic range are described and examples of data are presented.

Supported by: *ONR Contracts N00014-74-C-0262; NR 083-004 and N00014-70-C-0205; NR 084-325.*

INSTRUMENTATION

*SURFACE CURRENT MEASUREMENTS
USING A SHIP-TOWED LOG*

David S. Bitterman, Jr.

A joint program between Woods Hole Oceanographic Institution and the Institute of Oceanographic Sciences (U.K.) is in progress to develop a ship-towed log for use in measuring ocean surface currents. The ship's position is first calculated by vector averaging its speed and heading through the water as measured by the towed log. This position is then compared to its true position as determined from a reference navigation system such as a satellite navigator and attributing any difference to the current encountered by the ship between two true position fixes

The log will consist of a towed sensor package and a shipboard data logger to record the

data for later analysis ashore. The towed sensor package will contain an electromagnetic speed sensor; a compass; and roll, pitch, temperature and pressure sensors.

Published in: *POLYMODE News* #40, Dec. 16, 1977.

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

AUTONOMOUS LISTENING STATION STATUS REPORT

Albert M. Bradley

A figure of merit is established for the performance of the Autonomous Listening Station. It is able to track both 700 m and 2000 m *POLYMODE* Floats out to at least 1300 km.

Published in: *POLYMODE News* #40, Dec. 16, 1977.

PROPOSED WINCH AND CABLE SYSTEM FOR LARGE CORING OPERATIONS

Alan H. Driscoll and Arnold G. Sharp

Recent discussions during an engineering workshop on deep sea coring technology centered on the requirement of the scientific community for a large piston-type coring apparatus capable of recovering the upper 50 meters of bottom sediment. It was concluded that there is a need for more powerful winches and larger cable diameters than those available on most oceanographic ships. Present large coring operations are limited to the few ships having permanently installed winches capable of handling the heavy equipment weights and pullout forces encountered. A portable winch/cable system having its own power source and usable on more than one vessel, is considered a feasible and attractive alternative. The present paper considers the possibilities of this concept, and outlines in detail a system employing a double drum traction winch with a separate storage drum.

Technical Memorandum.

Supported by: *Sandia Document No. 07-7923.*

FLOAT PROGRAM TECHNICAL PROGRESS REPORT

Douglas C. Webb

The technical aspects of the *POLYMODE* float program are summarized, particularly the equipment field trials, the procurement program, and the development and test program for the Autonomous Listening Station.

Published in: *POLYMODE News* #36, Sep. 30, 1977.

Supported by: *NSF Grant OCE 75-18931 A02.*

FURTHER THOUGHTS ON LOCAL DYNAMICS EXPERIMENT

Douglas C. Webb

A technical approach to the observation of oceanic profiles is discussed. A streamlined body containing profiling equipment, driven by gravity and buoyancy, and able to steer itself to a capturing station near the ship is suggested together with a simple analysis of the performance potential in two versions of the Local Dynamics Experiment as proposed by McWilliams and Leetma.

Published in: *POLYMODE News* #34, Sep. 2, 1977.

Supported by: *IDOE Grant OCE 18931 A-2.*

TWO OCEANOGRAPHIC RELEASES

Albert J. Williams 3rd
and Kenneth D. Fairhurst

A high-reliability, dual-mode release has been used on untethered, midwater vehicles successfully since 1970. This device is operated by electrical signal or by hydrostatic pressure.

A second release which is self-contained and includes a relocation pinger has been designed for precisely timed release at minimum cost. The release function in this device occurs after the preset time by electrical corrosion of a wire link. This release has been used to recover sediment tray arrays.

Supported by: *ONR Contracts N00014-74-C-0262; NR 083-004 and N00014-66-C-0241; NR 083-004, and NOAA Grant 04-6-158-44072,*

MEASUREMENT OF THE VERTICAL FLUX OF PARTICULATE ORGANIC MATTER WITH A FREE-DRIFTING SEDIMENT TRAP

Nicholas Staresinic, Albert J. Williams,
Gilbert T. Rowe and Daniel Shaughnessy III

A major energetic link between marine planktonic and benthic ecosystems is the vertical transport of particulate organic matter synthesized in the plankton. Measurements of this important flux have previously been made with moored sediment traps. *In situ* dye experiments conducted in Buzzards Bay, Massachusetts, suggest that, in a current at least as low as 15 cm/sec, the turbulent wake established over the entrance of such a device may severely bias both the quantity and quality of the settling material collected. Similar experiments indicate that a free-drifting sediment trap is not hampered by this problem and may thus be a superior sampler. In addition, the free-drifting system also permits 1) shallow depolyments

in deep water columns without the engineering problems associated with deep moorings and 2) tracking of particular water masses, such as upwelling plumes, river plumes or Gulf Stream rings.

Supported by: *WHOI Predoctoral Fellowship.*

OCEAN APPLICATION OF LASER DOPPLER VELOCIMETRY
William E. Terry, Jr. and Albert J. Williams 3rd

In April 1977 a shallow-water single axis laser-Doppler velocimeter was designed and built at the Woods Hole Oceanographic Institution. The sensitivity of the instrument was 1.44 kHz per cm/sec with a 2% error at all flow speeds. Examples of laboratory measurements include a flow of .17 cm/sec with a signal-to-noise ratio of 54 db. Measurements obtained in waters off the WHOI dock include a flow of 38.8 cm/sec with a S/N of 23.8 db. A time series of velocity measurements was made from a recorded signal showing a temporal resolution of better than 10 Hz.

Published in: *POLYMODE News #28, May 1977.*

Supported by: *NSF Grant OCE 76-10523.*

*DESCRIPTION AND TEST OF A FISHING TRAWL
AND NET RESISTANT BOTTOM MOUNTED CURRENT
METER, WITH DIVERLESS SURFACE DEPLOYMENT
AND RECOVERY CAPABILITIES*

Clifford L. Winget

The research effort was performed to design, construct and demonstrate a structure that would support conventional current meters on the bottom in near coastal waters, be deployed and recovered without the use of divers, and provide an anchoring system that would minimize the loss rate and damage resulting from encounters with commercial fishing gear. The report covers in detail, all preliminary design concepts, the prototype design, construction details, weight, handling and current drag characteristics, deployment and recovery methods, and includes a discussion on design improvements based on experience obtained during sea trials.

Technical Memorandum.

Supported by: *ONR Contract N00014-76-C-1002.*

*OPERATOR PERFORMANCE IN UNDERSEA MANIPULATOR
SYSTEMS: STUDIES OF CONTROL PERFORMANCE
WITH VISUAL FORCE FEEDBACK*

Clifford L. Winget

The study was conducted to identify and evaluate selected design variables in undersea

manipulator systems with force feedback capability. The objective was to develop relationships between selected force feedback variables and operator control performance. A comprehensive series of engineering tests which describe response characteristics of experimental manipulator systems were completed.

Man-in-the-loop experiments were conducted to evaluate the relative merits of a highly compliant unilateral position control manipulator, and a similar system having visual meter read-out of applied forces. A group of selected tasks simulated typical work patterns presently being performed by undersea manipulators.

Supported by: *ONR Contract N00014-74-C-0179; NR 196-131.*

*INTERPRETATION OF VELOCITY PROFILES MEASURED
BY FREELY SINKING PROBES*

Peter J. Hendricks and George Rodenbusch

For most freely sinking instruments that measure horizontal velocity, it is necessary to understand the response of the vehicle to the flow to properly 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. The horizontal velocity of the vehicle is shown to be the low pass of the true current profile. The filter has a simple pole at a wave number that does not depend on the sink rate. Second, when there is a horizontal velocity sensor on the vehicle, the sensor may be displaced from the vehicle's center of mass. In this case there is a phase difference between the measured profile and the vehicle motion which may be accounted for. The third effect arises when the drag on the vehicle cannot be adequately modeled as a point force. The effect of the distributed drag force is only significant for high wave number variations.

These 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.

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

MOORINGS

HEAVE AND ROLL RESPONSE OF FREE FLOATING BODIES OF CYLINDRICAL SHAPE

Henri O. Berteaux, Roger A. Goldsmith
and Walter R. Schott, III

The following report describes a computer solution to help predict the heave and roll response of free floating bodies of cylindrical shape when excited by random seas with known spectra.

The basic concepts of harmonic analysis and statistics used in the method are first briefly reviewed. The report then presents a detailed derivation of the linear heave and roll response amplitude operators, that is the expressions of the vertical and angular displacements produced by a simple harmonic wave of one foot amplitude.

The second part of the report reviews the computation procedure and the program's logic. It gives a detailed set of instructions for the program users, reviews the program's capabilities and limitations, and presents three case studies.

The heave and roll response programs are written for use with Xerox Sigma 7 computers. Program listings are given in the appendix.

Supported by: *ONR Contract N00014-75-C-1064; NR 294-004 and NOAA.*

DYNAMICS OF THE INCLINING SPAR CURRENT SENSOR

George Rodenbusch and James W. Mavor, Jr.

This report describes the analysis of the governing equations of an inverted spar pendulum in current and waves which is dynamically similar to an inclining spar current meter. An equivalent linearization of the nonlinear bluff body drag term is described, and the results of the linearization are compared to a digital simulation. It is observed that the linearization performs well (within 4%) in predicting the mean square response in large currents, and less accurately (within 10%) when there is little or no current. The predicted shape of the spectrum is however less accurate for large currents where some frequency shifts in response have occurred.

Also included in the report is a discussion of proposed prototype tests of the current measuring spar as well as a description of progress in design of a vertically cycling instrument platform to be used for measuring current profiles during prototype test of the inclining spar.

Supported by: *NOAA Contract 04-6-158-44106.*

THE MOORING DYNAMICS EXPERIMENT -- A MAJOR STUDY OF THE DYNAMICS OF BUOYS IN THE DEEP OCEAN

Robert G. Walden, Lt. Donald H. DeBok,
Dallas Meggit, John B. Gregory
and William A. Vachon

Measurements of acceleration, pressure, temperature, tension and orientation were taken of five different deep-sea mooring configurations. Separate measurements of wind, current and waves were made to specify the environmental forcing functions. The experimentally derived data provides a base for use in validation of dynamic analytical models of deep-sea moorings. The experiment was conducted at an acoustic tracking range in the Pacific Ocean.

Published in: *Offshore Technology Conference Proceedings of 1977.*

Supported by: *Nat'l. Data Buoy Office (NOAA) and ONR Contract N00014-75-C-1064; NR 294-004.*

VALIDATION TESTING OF THE DOCMS INTERMEDIATE MOORING

Robert G. Walden, Clayton W. Collins, Jr.,
Peter R. Clay and Patrick O'Malley

A Deep Ocean Current Measurement System (DOCMS) was developed for the U.S. Naval Oceanographic Office under a contract with the U.S. Naval Facilities Engineering Command. A test of this mooring was made at the Pacific Missile Range Barking Sands Facility, Hawaii, to validate the design predictions. The motions of the mooring, both predicted and measured are tabulated and show good agreement. Current measurements were made from current meters on the DOCMS and on a nearby intermediate mooring. Current measurements from the surface to 500 meters were also obtained using an acoustic dropsonde. Acoustic pingers on the mooring were tracked in X, Y and Z coordinated by the range to provide data on the mooring motions and shape.

Supported by: *ONR Contracts N00014-75-C-1064; NR 294-044 and N00014-76-C-0197; NR 083-400 and NFEC Contract N62477-76-C-0046.*

A COMPILATION OF MOORED CURRENT METER DATA AND ASSOCIATED MOORING ACTION DATA FROM MOORING 592, Vol. XIV (1976 Data)

Susan A. Tarbell, Richard E. Payne
and Robert G. Walden

Summaries of moored current meter data from one mooring set and retrieved in 1976 near St. Croix by the Woods Hole Oceanographic

Institution are presented. The averaged current data are presented as statistics, spectral diagrams, plots of vector and scalar quantities versus time. Horizontal and vertical mooring motion data are also presented.

STATISTICS APPLIED TO OCEANOGRAPHY

FAUNAL CHANGES WITH DEPTH IN THE DEEP-SEA BENTHOS

J. Frederick Grassle, Howard L. Sanders,
and Woollcott K. Smith

A single method, the normalized expected species shared measure of similarity or NESS, is used to measure faunal change with depth for gastropods, cumaceans, polychaetes and ophiuroids. Each group has a characteristic pattern of zonation on the Gay Head - Bermuda transect, with the greatest changes in faunal composition occurring on the outer margins of the continental shelf and between upper slope and middle slope depths. Changes in cumacean species with both depth and distance between ocean basins are compared for Eastern and Western basins of the North Atlantic.

Supported by: *Pew Memorial Trust*.

SAMPLING PROPERTIES OF A FAMILY OF DIVERSITY MEASURES

Woollcott Smith and J. Frederick Grassle

A family of species diversity measures proposed by Hurlbert (1971) is defined as the expected number of species in a random sample of m individuals from a population. For $m = 2$ this measure is equivalent to Simpson's diversity index. For larger m , the measure is increasingly sensitive to rare species. In this paper we use unbiased estimation theory to obtain a minimum variance unbiased estimator for this family of diversity measures. An unbiased estimator of the sampling variance is also obtained. These results are then used to partition the variation in sample diversity between random sampling error and local variation community diversity.

Published in: *BIOMETRICS* 33, June 1977.

Supported by: *NSF Grant GA-36554*.

HORIZONTAL DISTRIBUTION OF PUMPED ZOOPLANKTON DURING A CONTROLLED ECOSYSTEM POLLUTION EXPERIMENT: IMPLICATIONS FOR SAMPLING STRATEGY IN LARGE-VOLUME ENCLOSED WATER COLUMNS

Isabelle P. Williams, Victoria R. Gibson
and Woollcott K. Smith

A large-volume pump system was used to collect zooplankton samples from several locations in three 1300 m³ plastic enclosures (CEEs) in Saanich Inlet, British Columbia. The horizontal distribution of three groups of zooplankton (*Pseudocalanus*, *Oithona* and copepod nauplii) was analyzed. Although the distribution of the organisms was demonstrated to be non-random, tests failed to show any consistent patterns of abundance. It was concluded that the horizontal distribution of zooplankton in the CEEs was not significantly influenced by the location of the sampling position (side of enclosure vs center, etc.); or by any external factor, such as weather condition.

Published in: *Marine Science Communications*.
1977. (Also refer to Page B-27)

Supported by: *NSF Grant OE 74-0515 A01*.

GENERAL

ALTERNATIVE ENERGY: INSTITUTIONAL ROLES IN THE U. S. A.

James W. Mavor, Jr.

Local initiatives for institutional change are the mainstay of the United States effort to adapt to new sources of energy. A hopeful scenario of the future follows an ecological rather than an economic model and sees regionalization of society in response to the distribution and types of energy source.

Published in: *Proc. Conf. on Appropriate
Technology and Institutional Change*,
Newcastle, England, Sept. 1977.

INTERPRETATION OF OCEANOGRAPHIC DATA FOR OTEC DESIGN

James W. Mavor, Jr., Henri O. Berteaux,
James R. McCullough, Arthur R. Miller
and Samuel W. Smith, Jr.

Ocean characteristics are interpreted within the framework of two broad and fundamental design criteria for ocean thermal energy conversion (OTEC) plants. They are the thermal resource and its conversion, and the structural integrity of the plant. The four critical issues raised by uncertainties about the oceanic environment are: effects of biofouling and corrosion on the heat exchanger, effects of temperature and flow variability on plant efficiency.

storm and hurricane survival, and prolonged (40 years) structural integrity at sea. Some preliminary conclusions can be drawn. The monthly mean temperature resource at candidate sites is known, OTEC plants located at latitudes greater than 25° may provide only transient operation, knowledge of extreme currents is generally inadequate, and recirculation of the intake warm water may be avoided by design of a discharge in the thermocline. Design justification for a long-term, site-specific oceanographic measurement program is given and it is recommended that the OTEC-1 Test Platform be used for measurements both for design and for environmental impact assessment.

Supported by: *ERDA Contract EG-77-S-02-4293.*

*INTERPRETATION OF OCEANOGRAPHIC DATA
FOR THE DESIGN OF OCEAN THERMAL ENERGY
CONVERSION PLANTS*

Lloyd R. Lewis and James W. Mavor, Jr.

The design of an Ocean Thermal Energy Conversion (OTEC) plant requires oceanographic measurements at the specific site to a fine level of detail over a time interval and with a frequency sufficient to assure optimum configuration and performance. A part of the design process is continuous evaluation of the oceanic data and matching it to the needs of design, construction and test.

Of the great quantities of oceanographic data available at likely OTEC sites, little was acquired with the objective of an OTEC plant. A structure of such large size, mass and involving such large mooring loads and large amounts of fluid flow is without precedent. Consequently, some data is of direct applicability, some needs interpretation, some may have insufficient accuracy or resolution and additional measurements may be required.

A program is underway to assess available ocean data, to design a plan and schedule to match ocean data to design, construction and test, to match existing data to this plan and to recommend a program of additional measurements.

Supported by: *ERDA Contract EG-77-S-02-4293.*

A PROPOSAL FOR HARNESSING WIND AND TIDE

James W. Mavor, Jr.

It is possible that Cape Cod and the Islands can be self-sufficient in renewable sources of energy.

In the future, an increasing share of our energy requirements are likely to be met by

many widely and thinly distributed renewable energy sources. These are available locally, either as low grade heat in the form of direct solar energy, as high grade heat from burning biomass (e.g. wood) or as the mechanical energy of wind and water flow. Wind and water flow, with which this article is concerned, are suitable for direct mechanical work and, with moderate losses, for electrical power generation. The pumping of water, which is historically one of the most common and efficient uses of wind power, may serve again in a substantial way to provide mechanical and heat storage.

In preparation for the future, it behooves the people in each community to assess their energy resources and the ways in which they can be used most appropriately. While cities will necessarily be dependent upon concentrated sources of energy such as oil and coal and possibly nuclear, there are many less populated regions that can be self-sufficient in renewable resources. Cape Cod and the Islands may be such a region.

Published in: *Falmouth Enterprise*, May 27, 1977 (Mail-Away Edition).

THE RIDDLE OF MZORAH

James W. Mavor, Jr.

The tumulus and rings of standing stones at Mzorah in Morocco are a puzzling provenance. Measurements show that the principal ring is a precise ellipse of proportions and possibly of dimensional units found heretofore only in Great Britain dated to the early second millennium B.C. and possibly earlier. It is furthermore the largest certain megalithic ellipse yet reported, consisting of 175 closely spaced menhirs. Astronomical and calendrical significance is strongly suggested but not conclusive. Aggradation of the river valley leading to Mzorah and change in sea level indicate that there was probably a navigable estuary leading to the monument in pre-Roman times which may have related to important sea voyages.

The possibility of a Bronze Age date for the Mzorah ellipse is examined and cultural ties between Morocco and Britain in prehistoric times are inferred. Ancient and medieval texts are cited which possibly relate to the monument and its cultural affinities with the east and north.

Published in: *AMLOGAREN*, Yearbook of Inst. Canarium, Akad. Druck und Veranstaltung Graz, Austria, Dec. 1977.

INFORMATION HANDLING

Melvin A. Rosenfeld and Thomas A. Davies

This chapter includes the complete history and evolution of the methods used over the past ten years for archiving, processing and publishing the voluminous data collected by the JOIDES Deep Sea Drilling Project. We describe the functions of the Science Services Section at DSDP and trace the course of data from the point of collection to inclusion in publications and/or inclusion in a searchable data base. Also explained are the various aids that have been developed to assist researchers in locating desired core material and data.

*RANGES AND EXTREMES OF THE NATURAL ENVIRONMENT
RELATED TO DESIGN CRITERIA FOR
OCEAN THERMAL ENERGY CONVERSION PLANTS*

Arthur R. Miller
(A Technical Report)

The distributions and amounts of the warm water temperature resource in the Caribbean - Gulf of Mexico region are linked with the wind field. Wind-induced "upwelling" or cooling of surface waters occurs seasonally off the Gulf Coast of the United States and perennially off the Caribbean coast of South America, apparently related to the north-south components of wind. Monthly means of temperature and wind fields are presented together with annual averages obtained from Surface Marine Observations representing over thirty years of observations. There is sufficient temperature resource in the area to operate Ocean Thermal Energy Conversion plants but to avoid re-circulation problems it is suggested that mixed discharge of waste waters to depths of about 200 meters be allowed for in the design of such structures.

PHYSICAL OCEANOGRAPHY

P0-1

DEPARTMENT OF PHYSICAL OCEANOGRAPHY

L. Valentine Worthington, Department Chairman

OCEAN CIRCULATION

SALT AND MASS FLUX IN
THE ATLANTIC EQUATORIAL UNDERCURRENT

Eli J. Katz, John G. Bruce and Brian D. Petrie

A zonal study of the equatorial undercurrent is described from meridional current and hydrographic sections between 10°W and 33°W , obtained from the R/V *Atlantis II* during June and July 1974. The observations were a part of GATE, the Global Atmospheric Research Program - Atlantic Tropical Experiment. It is shown that the undercurrent carries with it (and is often synonymous with) a salinity anomaly. Meridional sections contain as much as $4 \times 10^7 \text{ g cm}^{-1}$ of anomalous salt, decreasing downstream. The volume transport of the undercurrent is estimated to average $10^7 \text{ m}^3 \text{ s}^{-1}$, increasing by about 30% downstream from 33°W to 16°W . East of 16°W the eastward pressure gradient is absent and the volume transport decreased substantially. The rate of salt flux out of the undercurrent, beginning at 28°W , is $7\text{-}1\frac{1}{4} \text{ g cm}^{-1} \text{ s}^{-1}$. Meridional diffusion is not considered to contribute significantly to this loss because of the absence of downstream spreading of the saline core. Instead the diffusion is assumed to be balanced by meridional convergence of flow into the undercurrent. A convergence velocity of 2 cm s^{-1} balances the increased mass transport which in turn suggests a lateral eddy diffusion coefficient of $2 \times 10^7 \text{ cm}^2 \text{ s}^{-1}$. The vertical flux from the undercurrent to the pycnostad, increasing the pycnostad's salinity and temperature from $35.20 \text{ }^{\circ}\text{‰}$ and 12.3°C at 33°W to $35.44 \text{ }^{\circ}\text{‰}$ and 14.1°C at 10°W , is estimated to be $2 \text{ g cm}^{-1} \text{ s}^{-1}$. The latter is equivalent to the vertical eddy diffusivity of $1 \text{ cm}^2 \text{ s}^{-1}$. The remainder of the salt flux is assumed to be diffused upward into the surface layer, which is equivalent to an eddy diffusivity of $1\text{-}1\frac{1}{2} \text{ cm}^2 \text{ s}^{-1}$. The Richardson number above and below the saline core of the undercurrent is often low (less than 0.5), suggesting vertical eddy viscosities of 1 to 10 times the eddy diffusivities.

Supported by: NSF Grant ATM73-00344.

BOTTOM WATER TRANSPORT
THROUGH THE SOUTHWEST INDIAN RIDGE

Bruce A. Warren

Properties measured on a line of hydrographic stations in the southeastern Madagascar Basin, parallel to the Southwest Indian Ridge, show clear evidence of bottom flow from the Crozet Basin into the Madagascar Basin through fractures in the Ridge. Its rate

of volume transport is estimated at about $6 \times 10^6 \text{ m}^3 \text{ s}^{-1}$, comparable with previous estimates of the transport of the deep western boundary current off Madagascar. It is inferred that the latter current derives entirely from the Crozet Basin, and not at all from the Mozambique Basin to the west.

In press: *Deep-Sea Research*.

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

THE INTENSIFICATION OF THE GULF STREAM
AFTER THE WINTER OF 1976-1977

L. Valentine Worthington

The unusually cold winter of 1976-1977 caused deep ($>600 \text{ m}$) mixed layers in the region south of the Gulf Stream. It is suggested that, as a result of this, the main thermocline was deeper than usual in this region. It follows that, if the main thermocline was deeper, the baroclinic volume transport was greater. The computed volume transport last winter was $95 \times 10^6 \text{ m}^3 \text{ s}^{-1}$ relative to the 2000 db surface. This was the largest ever computed from that surface. The large transport is attributed, in part, to the severity of the winter.

Published in: *Nature*, 270(5636), 415-417, 1977.

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

RINGS, EDDIES

DISTRIBUTION AND MOVEMENT OF GULF STREAM RINGS

David Y. Lai and Philip L. Richardson

The distribution, number and movement of cyclonic Gulf Stream rings was estimated from an analysis of 50,000 temperature records obtained from the National Oceanographic Data Center and Fleet Numerical Weather Central. The data were taken from 1970 through September 1976 in the region bounded by $20\text{-}40^{\circ}\text{N}$ and $50\text{-}80^{\circ}\text{W}$. Additional ring observations from other sources were also used. Twenty-five ring time series, together with 26 single ring observations were obtained; approximately 11 rings were found to exist at one time. Rings typically moved westward, turned southwest when close to the Gulf Stream and appeared to coalesce with the Stream near Florida. On the average, two rings per year moved down this path with a mean speed of 3 km per day and an estimated life span of 2-3 years. Although ring observations were concentrated in the

northwestern Sargasso Sea, several were documented east of 60°W. In addition to cold core rings several warm eddies were found south of the Stream; they consisted of at least a 150 m deepening of the main thermocline. The movement of anticyclonic rings north of the Stream was also determined; approximately three exist at a single time and they move westward with a mean speed of 5 km per day.

Published in: *J. Physical Oceanography*,
7(5): 670-683, 1977.

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OCE75-08765 to W.H.O.I.

*LARGE CYCLONIC RINGS FROM
THE NORTHEAST SARGASSO SEA*

Michael S. McCartney, L. Valentine Worthington
and William J. Schmitz

XBT observations have revealed large cold core cyclonic current rings to the east of 60°W in a region mechanical BT observations (Parker, 1971) indicated to be devoid of rings. As a class these rings are larger than typical Gulf Stream rings that form and drift west of 60°W. The typical diameter (15°C at 500 m) there is around 100 km, while the eastern Sargasso rings are 200 km and more in diameter. Several of these eastern rings were observed on each of four cruises in the northern Sargasso Sea in 1974 and 1975. The overall picture of the region east of 60°W obtained was a very noisy one, dominated by large diameter, large amplitude eddies. One of the eastern rings was seen in all four cruises, and observed to drift westward for over 730 km at an average speed of 4.4 km/day, starting at 56°30'W and 34°40'N and passing north of Bermuda. The character of the dissolved oxygen anomalies in the cores of the eastern rings, suggests a possible formation region at the eastern end of the Sargasso Sea gyre, around 40°W. Hence the eastern rings may have already been a year old when first observed in November 1974. A single deep hydrographic section showed the center of the deep circulation to lie considerably further southwest than the near surface circulation center, although this could be a distortion due to a large seamount. Moored current meter data suggests a level of no motion within eastern rings at about 2000 m, giving a weak anticyclonic circulation of $4 \times 10^6 \text{ m}^3/\text{sec}$ below that level, compared to the $45 \times 10^6 \text{ m}^3/\text{sec}$ cyclonic circulation above 2000 m. On several occasions smaller scale upward displacements of the thermal structure were seen at the sides of eastern rings. It is not known whether these represented interactions with smaller rings, or some breakdown of the circular symmetry.

Reference: *Deep Sea Research*, 18, 1971,

In press: *J. Geophysical Research*.

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

*SPACE AND TIME SCALES OF MESOSCALE MOTION
IN THE WESTERN NORTH ATLANTIC*

James G. Richman, Carl Wunsch
and Nelson G. Hogg

From moored data, primarily temperature, of the Mid-Ocean Dynamics Experiment (MODE-I) and its successor experiments, we find a statistical description of the meso-scale variability. In the MODE-I area itself, the spectral characteristics of the thermocline and deep water are different. The thermocline is conveniently described as made up of three spectral bands: a "low-frequency" band dominated by zonal velocity fluctuations, an "eddy-containing" band in which the velocity field is nearly isotropic, and a "high-frequency" band consistent with models of geostrophic turbulence. In the deep water, the zonal dominance at low frequencies is not apparent, and there is enhanced energy at periods of 20-50 days. Vertical structure scales with WKBJ approximation in the high-frequency band but not in the lower frequencies where low vertical modes dominate the motion. Linear models do not adequately describe the data in the MODE-I region. Differences between rough and smooth topography regions are only clearly seen at 1500 m where there is a loss of energy consistent with a reduced barotropic motion. Other differences, while apparently real, are small.

It is found, consistent with results of Schmitz (1976a), that the MODE-I region is atypical of the mid-ocean in that large changes of energy level are found elsewhere. A region due east of MODE-I has slightly reduced kinetic energy levels in the main thermocline, but deep energy levels are much lower. Potential energy is less variable than kinetic; in the eastern region the frequency spectra change structure slightly. Linear models may be more adequate there.

With more than two years of data no statistically significant heat flux was found in the MODE-I area, except for a weak zonal flux in the deep water. There is no direct evidence for baroclinic instability as a significant mechanism of eddy generation; the Gulf Stream is a possible, if unconfirmed, source.

Reference: Schmitz, 1976. *J. Geophys. Res.* 81.

Published in: *Rev. of Geophys. and Space Phys.*
15(4): 385-420, 1977.

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and N00014-76-C-0197; NR 083-400.

OBSERVATIONS OF THE VERTICAL DISTRIBUTION
OF LOW FREQUENCY KINETIC ENERGY
IN THE WESTERN NORTH ATLANTIC

William J. Schmitz, Jr.

Eddy kinetic energy in the western North Atlantic is observed to increase approaching the Gulf Stream System from the interior of the subtropical gyre at depths from 500 to 4000 m along 55°W longitude; by a factor of 30 in the thermocline and by over two orders of magnitude at 4000 m, and at this latter depth tends to decrease moving up the continental rise from the Gulf Stream. The relative vertical distribution of eddy kinetic energy is found to be less depth dependent approaching the Gulf Stream System (with increasing energy level?). The shape of the kinetic energy frequency spectrum varies with depth and with geographical position; although spectral estimates in the thermocline in the MODE-I area (28°N, 70°W) are dominated by longer time scales, at a site near the Gulf Stream (37°30'N, 55°W) the thermocline spectrum is more weighted toward the temporal mesoscale (~100 days) that dominates at 4000 m depth in the MODE I area. Spectral estimates at depth appear to be further weighted toward shorter time scales approaching the continental rise, slope, and shelf.

If the eddy kinetic energy is divided into pieces with periods less than 100 days in one band and greater than 100 days in the second, then: (1) The relative vertical distribution of eddy kinetic energy near the Gulf Stream does not differ significantly from band to band, whereas in the MODE-I region the lower frequencies are much more depth dependent than the higher; (2) The relative vertical distribution of eddy kinetic energy for periods less than 100 days is not appreciably different at the two locations; (3) The relative vertical distribution of eddy kinetic energy at the lower frequencies in the MODE-I region does not differ significantly from the total distribution at a site further into the interior of the gyre.

Time averaged currents at all depths where data are available show a relatively narrow and comparatively depth independent return flow for the Gulf Stream System along 55°W; transporting roughly $70 \times 10^6 \text{ m}^3 \text{ s}^{-1}$ westward, with about $25 \times 10^6 \text{ m}^3 \text{ s}^{-1}$ relative to the bottom and approximately $45 \times 10^6 \text{ m}^3 \text{ s}^{-1}$ associated with the "bottom transport".

In press: *J. Marine Research*.

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SURFACE LAYER PROCESSES
AND METEOROLOGY

WINTER CIRCULATION IN THE WESTERN
GULF OF MAINE: PART I, COOLING
AND WATER MASS FORMATION

Wendell S. Brown and Robert C. Beardsley

The mean circulation on the northeast continental shelf in the region of the Gulf of Maine is discussed in terms of a simple box model, based on volume transports and mean salinities estimated from existing data. The results of this calculation indicate that warm salty water from the continental slope must mix with colder, fresher water at intermediate depths within the Gulf. Field measurements obtained as part of a study of the winter circulation in an offshore region in the western Gulf of Maine suggest that winter storms may be responsible for most of this vertical mixing. Ten one-day hydrographic cruises were conducted between the passage of seasonal storms from November 1974 to January 1975. A description of the early winter evolution of the density field was thus obtained concurrently with moored measurements of current, temperature, and bottom pressure and coastal measurements of sea level and atmospheric variables. The principal vertical mixing process observed during this period was an intermittent overturning of the near surface water caused by surface cooling by offshore winds. The observed vertical homogeneity suggests that the fresher near surface Gulf of Maine water and the more saline deep basin water are frequently mixed during the early winter in the western region to produce Gulf of Maine intermediate Water (MIW).

In press: *J. of Physical Oceanography*.

Supported by: NSF Grants DES 75-03992,
OCE 76-02190, DES 74-03001 and
OCE 76-01813.

SPATIAL AND TEMPORAL VARIATION OF THE
WIND STRESS OFF THE SOMALI COAST

John G. Bruce

Wind observations from ships along the sea lane off the Somali Coast are used for estimating the seasonal increase in wind stress during the southwest monsoon. The stress has a relatively large maximum (~4-6 dynes cm^{-2}) in the region between 8°N to 12°N during June, July, and August. Maximum values of the zonal wind stress curl occur about 6°N to 8°N. During this monsoon period a large scale eddy (~600 km in diameter) or eddies occur here in the Somali Basin. Wind stress averages (1922-1972) for the northwestern Indian Ocean are also given. Yearly southwest monsoon averages for the region subjected to

the strong monsoon winds show that stress components may vary from year to year by nearly a factor of 2.

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STRUCTURE, TURBULENCE, FLUXES, AND TRANSFORMATIONS OF A MARITIME COLD FRONT DURING AMTEX

Andrew F. Bunker

To analyse features of maritime cold fronts measurements of many meteorological variables were made at six levels from the NCAR Electra aircraft flying through a cold front moving southeast from Okinawa during AMTEX. The front was relatively weak and atypical in that it was double and no middle or high clouds existed above a stratocumulus shield at 2 km. The history of the fronts is given and the structure described. Characteristics of several frontal air masses are determined from flight and radiosonde data. Mixing, primarily vertical by cumulus convection, between the various air masses is demonstrated. Regions of upward motion ahead of the fronts located by aircraft inertial navigation system measurements and from divergence of winds agreed well and confirmed the double structure of the front. Local areas of frontogenesis are found ahead of each front. Averaged over the entire system, weak frontolysis was occurring primarily as a consequence of the warming of air behind the fronts. Both positive and negative fluxes of heat and water vapor occurred within the frontal zone as a result of turbulent transport, direct cumulus convection, over shooting of equilibrium levels, and subsidence of cloud remnants. Normalization of velocity spectra in the frontal zone by height times energy dissipation and frequencies by height over aircraft speed gives a universal spectral pattern indicating the dominance of generation of turbulent energy by shearing processes. Spectra observed within cold air behind the front fit the shapes and non-dimensional values characteristic of well-mixed air heated from below and capped by an inversion, indicating the dominance of heating as a source of turbulent energy.

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Supported by: NSF Grant ATM 73-00421.

UPDATED CHARTS OF THE MEAN ANNUAL WIND STRESS, CONVERGENCES IN THE EKMAN LAYERS, AND SVERDRUP TRANSPORTS IN THE NORTH ATLANTIC

Ants Leetmaa and Andrew F. Bunker

From the wind stress computation of Bunker (1976) for the North Atlantic, the annual mean and seasonal vertical velocities which result from convergences in the Ekman Layers are computed. Charts of the geostrophic and total transport (geostrophic plus Ekman) are constructed using the Sverdrup relationship. Of particular interest are an intense current leaving the coast at the point where the Gulf Stream separates and a cyclonic gyre north of the Stream in this area. Good agreement exists between the computed features of the large scale circulation patterns and transports and the observed ones. Close correspondence exists between the predicted path of the Gulf Stream, the observed path, and the maxima in the wind stress.

Reference: *Monthly Weather Review*, 104(9).

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

THEORETICAL MODELS

A SIMPLE THEORETICAL MODEL FOR THE FLOW OF AN ESTUARY ONTO A CONTINENTAL SHELF

Robert C. Beardsley and John Hart

A simple theoretical model is developed to describe the steady flow of an estuary onto an adjacent continental shelf. A two-layer density stratification is assumed for the shelf water and the fluid motion is driven by the positive (upper-layer) and negative (lower layer) mass fluxes associated with a pair of point sources located at the mouth of the estuary. The dynamics are linear and include the effects of Coriolis acceleration, turbulent friction, and bottom topography. Analytic solutions for the one-layer single source problem are found for two special depth profiles. A boundary layer solution is found for the power law depth profile $h(y) = \alpha y^k$ and a global solution is found for the log law profile $h(y) = H_0(1 + \alpha \ln(y/L_b))$ for small $\alpha \ll 1$. Both solutions indicate that the far field flow is asymmetrically concentrated towards the right-hand coast in the northern hemisphere, a consequence of the basic balance between topographic vortex stretching and frictional spin down. This mechanism also applies when a constant alongshore current is present. In the two-layer case, the flow in the upper layer generally tends to be concentrated towards the left-hand coast since the upper fluid feels a) the interface and not the bottom topography, and b) the interfacial drag exerted by the lower fluid towards the right-hand coast. A brief com-

parison is made between model predictions and observations for the Hudson and Chesapeake Bay estuaries.

In press: *J. Geophysical Research*.

Supported by: NSF Grants DEW 74-14356, DES 74-03001 and OCE 76-01913.

SOME THEORETICAL AND LABORATORY MODELS OF SHELF-FLUSHING PROCESSES

John A. Whitehead, Jr.

Some linearized solutions are presented for the theoretical model of shelf circulation posed by Stommel and Leetmaa (1972). In the limit of rapid rotation, the density flux across the shelf is predicted to be proportional to

$$\frac{u_0^2}{fD} \frac{\partial \rho}{\partial x} d\nu$$

where u_0 is the sum of the buoyancy-driven plus a suitably defined wind-driven velocity, $\partial \rho / \partial x$ is an across-shelf density gradient, d is depth, f is Coriolis parameter, ν is viscosity and D is diffusivity of the density. If the viscosity and diffusivity are due to turbulence, and if the water is not too stratified, $\nu = D$. The above formula then predicts that the density flux across the shelf is independent of the diffusive properties of the turbulent shelf water. The predictions are compared with laboratory experiment, with agreement in some parameter space and the observation of instabilities in other space. Implications of the solutions and the experimental observations of instabilities upon some observed features of shelf circulation are discussed.

Reference: *Proc. Nat. Acad. Sci. U.S.A.* 69.

Supported by: NSF Grant OCE 72-01562.

TURBULENCE AND MIXING, TOPOGRAPHIC EFFECTS

TURBULENT INTERFACE LAYERS

Gabriel T. Csanady

The "law of the wall" familiar from turbulent boundary layer theory has been extended to turbulent flow along a sharp density interface. The effective gravity of such an interface is an additional independent variable, so that in nondimensional form the "law of the interface" becomes a one-parameter family of curves. A convenient label for each curve is its "Keulegan parameter", a nondimensional combination of inner variables, which also plays a role in the theory of interfacial stability.

One important difference between the laws of wall and interface is that the velocity gradient at an interface is typically much less than the stress divided by molecular viscosity. Even in the nonturbulent core of an interface

the effective viscosity is appreciably higher than molecular. This finding is explained by the presence of viscous wavelets on the interface which contribute to momentum transfer through a combination of "sheltering" and the generation of an interfacial viscous boundary layer. A simple approximate theory based on these ideas reproduces the observed functional form of effective viscosity versus Keulegan parameter (a square root relationship for miscible fluids).

At interfaces with free surface energy, for low relative velocities, capillarity plays an important role. Capillary-gravity waves of minimum celerity become key agents of momentum transfer, so that effective interface viscosity comes to depend on surface tension.

The second major effect of variations of effective gravity is changing hydrodynamic roughness. The extent of this influence is governed by the buoyancy flux and also occurs over solid walls, although this has so far been ignored in the literature. Evidence from a variety of sources now suggests that hydrodynamic "roughness" is determined by the energy balance of turbulence very close to the wall. A simple approximate theory based on this postulate reproduces qualitatively the observed interface roughness changes.

Bulk relationships (drag, shear and mass transfer coefficients) for interfaces may be determined by matching inner and outer laws in the conventional manner. The most practical independent variables for the presentation of such laws appear to be a gravity to viscous force ratio (rather than Reynolds number) and a Keulegan parameter (rather than Froude number), both based on bulk external variables.

In press: *J. Geophysical Research*.

Supported by: Techniques Development Laboratory, NOAA Contract 6-35276 and Brookhaven Natl. Laboratory Contract 359133-S

ON THE STABILITY OF THE WINTER SHELF WATER/ SLOPE WATER FRONT SOUTH OF NEW ENGLAND

Charles N. Flagg and Robert C. Beardsley

The stability of a Margules front over steep topography is studied in an attempt to explain some wavelike features observed on the shelf water/slope water front south of New England. During winter, this front extends from the bottom near the 85 m isobath to the surface with a typical mean slope of 2×10^{-3} , corresponding to a geostrophic shear of about 10 cm/sec. A quasi-synoptic hydrographic survey of the New England shelf made during March, 1974, resolved a wavelike distortion of the front characterized by an 80 km alongshelf wave length. The

associated Rossby number based upon the along-shelf wavenumber and the vertical shear ($Ro = k(\Delta U)/2f$) is < 0.1 so that a perturbation analysis using the semigeostrophic approximation is possible. This approach allows the resulting equations to be cast into an ordinary eigenvalue problem which can be easily solved numerically. The effect of increasing the bottom slope is to destabilize some neutral modes and to stabilize other modes that had been unstable over flat topography. In general, however, the characteristic e-folding times of the unstable modes increases dramatically from 2-5 days for flat topography to 50-100 days for realistically steep topography. The observed wavelike features on the front are thus probably not caused by local baroclinic instability. However, we note that the front would be much more unstable over flat topography which may help explain why fronts of this type are confined to the shelf break region.

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DES74-03001 and OCE76-01813.

EDDIES, ISLANDS, AND MIXING

Nelson G. Hogg, Eli J. Katz, Thomas B. Sanford

As part of a field study of the relation between fine- and large-scale variations of water properties in the western North Atlantic, the waters in the vicinity of Bermuda were investigated in detail. Previous work in the area had revealed regions of intense temperature finestructure confined to the island's sides. Generally quieter levels of activity elsewhere in the mid-ocean have suggested that significant mixing might only occur at the ocean's solid and fluid boundaries. During the course of our investigation two Gulf Stream rings were found in the vicinity of the island. The exchange of water between them caused three regions of strong alongshore flow. In these three areas we find elevated levels of temperature fine-structure in the upper 800 m as measured by the variance in the temperature gradient normalized by the square of the mean temperature gradient over the interval. The normalized temperature variances on small scales (0.2-1 m) are most energetic in patches tightly bound to the island sides, whereas the fine-structure on larger scales (5-25 m) is also energetic away from the island in a region of outflow. Velocity profiles show that vertical scales shorten as one approaches the island, and the energy increases in the counterclockwise component. There is no correlation evident between the shear measurements of the internal wave field and the intensity of the finestructure. Possible mechanism for the production of finestructure are explored within the context of these observations.

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DYNAMICS OF DEEP WATER CANYONS

Carl Wunsch, Frances Stephenson Hotchkiss
and Robert C. Millard, Jr.

Using data from a recent hydrographic survey, we show that there is apparently very intense mixing occurring at the head of Hudson Canyon with dense water penetrating up canyon along the floor. We conjecture that this and other features, possibly including the geology of such large canyons on the east coast of the United States, are explainable as the result of the trapping of internal waves in the canyon and their subsequent breakdown near the canyon head. This breakdown serves to mix the water and suspend the sediment there.

Supported by: ONR Contract N00014-75-C-0291.

OTHERS

SOME EVIDENCE FOR BOUNDARY MIXING IN THE DEEP OCEAN

Laurence Armi

Profiles of salinity and potential temperature in the deep ocean are presented which suggest the characteristic signature of two complementary mixing processes: vertical mixing within ~50 m thick layers at boundaries and topographic features; lateral advection and eventual smearing of these mixed layers along isopycnal surfaces. The combined effect of these two processes is often parametrically disguised as a vertical eddy diffusivity in one-dimensional models. An estimate shows that the two processes can account for all the vertical mixing in the deep ocean without any vertical diffusion in the interior.

In press: *J. Geophysical Research.*

Supported by: ONR Contract N00014-76-C-0197; NR 083-400 and NSF Grant OCE76-81190.

MEASUREMENTS AND MODELS OF FINE-STRUCTURE, INTERNAL GRAVITY WAVES AND WAVE BREAKING IN THE DEEP OCEAN

Charles Curtis Eriksen

Measurements of horizontal and vertical current by propeller cluster current meters and temperature by thermistors mounted on a rigid array 8 m high and 20 m long moored in the oceanic main thermocline near Bermuda are interpreted in terms of thermocline-trapped internal wave modes in the

presence of temperature and velocity fine-structure. The array was deployed roughly 250 m off the sloping bottom in water roughly 900 m deep on three occasions.

Two-turning-point uniformly valid asymptotic solutions to the internal wave equation are developed to describe the wave functions. Mode decay beyond the turning point in depth or frequency produces a sharp cutoff in vertical current spectra above the local buoyancy frequency $N(z)$. An internal wave wavenumber-frequency spectral model $E(\alpha, \omega) = E(\omega/N_0)^{-2} (\alpha/\alpha_0)^{-2}$ describes vertical current spectra and ratios of potential energy to horizontal kinematic energy. The red wavenumber shape suppresses peaks in both these quantities at frequencies near $N(z)$. A dip in the vertical current spectra at 0.5 cph not predicted by the model appears related to the bottom slope.

Temperature fine-structure is modeled as a passive vertical field advected by internal waves. Quasi-permanent fine-scale features of the stratification and vertically short internal waves are indistinguishable in this study. The model of McKean (1974) is generalized to include fine-structure fields specified by their vertical wavenumber spectra. Together with the trapped internal wave model, moored temperature spectra, temperature vertical difference spectra, and coherence over vertical separations are described using a fine-structure vertical wavenumber spectrum $P_T(k) = A_T k^{-5/2}$ which agrees with other spectra made using vertical profiling instruments in the range 0.1 to 1.0 cpm.

Horizontal current fine-structure is also modeled as a passive field advected by vertically long internal waves. The model describes moored horizontal current spectra (least successfully at frequencies near $N(z)$) and finite-difference vertical shear spectra.

Contours of temperature in depth versus time indicate possible mixing events. These events appear concurrently with high shear and Richardson numbers $0.25 \leq R \leq 1.0$. Over a 7 m vertical separation a cutoff in R_i at 0.25 is observed, indicating possible saturation of the internal wave spectrum. Spectra of finite-difference approximations to shear and buoyancy frequency are dominated by fine-structure contributions over nearly the whole internal wave range, suggesting that breaking is enhanced by fine-structure. Breaking appears equally likely at all frequencies in the internal wave range.

Reference: McKean, J. *Phys. Oceanog.* 4.

In press: *J. Geophysical Research.*

Supported by: ONR Contracts N00014-67-0204-0047, N00014-75-C-0291; NR 083-157 and N00014-76-C-0197; NR 083-400.

HARMONIC ANALYSIS OF THE TIDE IN NANTUCKET AND VINEYARD SOUND

John A. Moody and Alfred C. Redfield

The form of the tide curves in Nantucket and Vineyard Sound is approximately reproduced by combining six tidal constituents calculated by harmonic analysis from records at eight positions.

The M_2 constituent varies in amplitude and epoch along the passage in a way which may be accounted for by the interference of waves entering from outside and traversing the passage in opposite directions. The M_4 constituent on the other hand resembles a standing wave having nearly the same amplitude and epoch at all positions within the sounds. While this suggests that the M_4 constituent is due to the direct action of the lunar tractile force on the local water within the sounds, no satisfactory explanation can be given to account for its amplitude and epoch.

Supported by: W.H.O.I. Education Office
and NOAA Office of Sea Grant #04-6-158-44016.

A POSSIBLE MECHANISM FOR THE FORMATION OF DISCRETE ISLANDS IN LINEAR ISLAND CHAINS

John N. Skilbeck and John A. Whitehead, Jr.

The existence of plumes (of thermally or chemically differentiated material) in the Earth's mantle has long been suggested as an explanation for the formation of island chains such as Hawaii. It is unclear, however, what mechanism operates within the mantle to produce the discrete islands in these chains. Mantle convection studies indicate that a "large-scale" shear flow exists beneath the plates and it is our suggestion that this shear and the buoyant uplift of the lower density plume material act together to produce a succession (in time) of discrete plumes. We describe a simple laboratory experiment designed to test this idea and give a theoretical explanation of the results. In addition, we present a crude calculation of a mantle with a low-viscosity shear zone and conclude that the observed spacing of the Hawaiian Islands requires such a zone to be less than about 80 km thick. This conclusion that a thin low-viscosity shear zone exists in the mantle has been reached by many geophysicists for a variety of different reasons. This fact indicates strongly that the mechanism discussed here may well be responsible for the formation of discrete islands in island chains.

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TECHNICAL REPORTS

*CMICE 76: A CURRENT METER INTERCOMPARISON
EXPERIMENT CONDUCTED OFF LONG ISLAND
IN FEBRUARY-MARCH, 1976*

Robert C. Beardsley, William C. Boicourt,
Lloyd C. Huff and Jon T. Scott

A current meter intercomparison experiment (called CMICE 76) was conducted about 6 km off the southern coast of Long Island near 40°47'N, 72°30'W during February and March, 1976. A total of 20 current meters were deployed on six moorings set in a roughly linear array parallel to the local coastline and topography. The instruments included the Aanderaa RCM-4, the AMF VACM, the Brookhaven National Laboratory spar buoy system utilizing cylindrical and spherical Marsh-McBirney electromagnetic sensors, the EG&G 850 and CT-3, and the Chesapeake Bay Institute modified ENDECO 105. Local mean water depth was 27.8 m and current meters were clustered near 4 depth levels (3.5 m, 7.4m, 15.7m, and 25.0 m). Wave data was also obtained at the array site and 10 m wind and tidal data was obtained from nearby coastal stations. Intercomparisons of 1 hr vector average velocities measured with similar instruments deployed near the same depth level indicated sufficient horizontal homogeneity that most differences in the observed current data have been attributed to real differences in instrument and mooring performance. Detailed discussions of the observed data, instrument and mooring characteristics and performance, and the effect of surface wave and wave-induced mooring motion on different measurement systems are presented.

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*WINTERTIME 1974-75 WESTERN GULF OF MAINE
EXPERIMENT DATA REPORT*

Wendell S. Brown, John A. Vermersch
and Robert C. Beardsley

Summaries are presented of basic hydrographic measurements and current, temperature and pressure measurements which were made from moored instruments as a part of the Wintertime 1974-75 Gulf of Maine Experiment which took place November 1974 to January 1975.

Prepared for: *NSF Grants DES 75-03992,
DES 74-03001 and OCE 76-01813.*

*BOUNDARY LAYER AND FRONTAL STRUCTURE
OVER THE EAST CHINA SEA*

Andrew F. Bunker, Principal Investigator

To analyze features of maritime cold fronts measurements of many meteorological variables were made at six levels from the NCAS Electra aircraft flying through a cold front moving southeast from Okinawa during AMTEX. The front was relatively weak and atypical in that it was double and no middle or high clouds existed above a stratocumulus shield at 2 km. The history of the fronts is given and the structure described. Characteristics of several frontal air masses are determined from flight and radiosonde data. Mixing, primarily vertical by cumulus convection, between the various air masses is demonstrated. Regions of upward motion ahead of the fronts located by aircraft inertial navigation system measurements and from divergence of winds agreed well and confirmed the double structure of the front. Local areas of frontogenesis are found ahead of each front. Average over the entire system, weak frontolysis was occurring primarily as a consequence of the warming of air behind the fronts. Both positive and negative fluxes of heat and water vapor occurred within the frontal zone as a result of turbulent transport, direct cumulus convection, overshooting of equilibrium levels, and subsidence of cloud remnants. Normalization of velocity spectra in the frontal zone by height times energy dissipation and frequencies by height over aircraft speed gives a universal spectral pattern indicating the dominance of generation of turbulent energy by shearing processes. Spectra observed within cold air behind the front fits the shapes and nondimensional values characteristic of well-mixed air heated from below and capped by an inversion, indicating the dominance of heating as a source of turbulent energy.

Prepared for: *NSF Grant ATM 73-0421.*

*FIELD EXPERIENCE WITH ACOUSTIC RELEASES
AT THE WOODS HOLE OCEANOGRAPHIC INSTITUTION*

Robert H. Heinmiller, Jr.
and Roderigue A. LaRochelle

The Buoy Project at the Woods Hole Oceanographic Institution has accumulated seven years of field experience with the acoustic release system built by American Machine and Foundry (AMF). In 1967, as a result of a testing program conducted to select a release system (Heinmiller, 1968) the AMF system was selected as the sole anchor-release device used on Buoy Project moorings. Through December of 1976

this system has been deployed a total of 328 times in various mooring configurations. While release failures are sometimes difficult to separate from other problems, particularly in the case of subsurface moorings, we have had excellent reliability.

Reference: *Heinmiller, WHOI Ref. No. 68-48.*

Prepared for: *ONR Contracts N00014-66-C-0241; NR 083-004; N00014-74-C-0262; NR 083-004; N00014-76-C-0197; NR 083-400; NSF Grants GX-29054 and IDO 75-03962.*

*CURRENT METER AND TEMPERATURE RECORDS
FROM THE WINDWARD PASSAGE*

William G. Metcalf, Marvel C. Stalcup
and Marguerite Zemanovic

During late 1973 and early 1974, current and temperature measurements were made close to the sill of the Windward Passage between Cuba and Hispaniola. In the course of *Atlantis II* Cruise 78 in November 1973 a brief bathymetric survey of the sill area was carried out followed by the anchoring of two arrays of current meters and temperature recorders. Hydrographic stations were occupied in the sill region to determine the temperature, salinity, oxygen and silicate characteristics of the water column. During *Knorr* Cruise 37 in February and March 1974, additional bathymetric and hydrographic station observations were made and the current meters and temperature recorders were recovered. In this report, some of the basic data from the moored arrays are presented.

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*THE NORTH ATLANTIC FINE AND MICROSTRUCTURE
CRUISE Knorr 52 AND Eastward 75-12*

Thomas B. Sanford and Nelson G. Hogg

In the fall of 1975 a three-ship, multi-investigator, ONR-sponsored study was made of the distribution of fine- and microstructure in the Northwest Atlantic (the North Atlantic Fine- and Microstructure Cruise). A variety of sophisticated, highly sensitive instrumentation was used to observe the small scale variability of temperature, salinity and velocity in the ocean. This report summarizes the cruise objectives, describes the instrumentation and gives information concerning the observations and data quality.

Prepared for: *ONR Contract N00014-74-C-0262; NR 083-004.*

*A COMPILATION OF MOORED CURRENT METER DATA
AND ASSOCIATED MOORING ACTION DATA
FROM MOORING 592, VOLUME XIV (1976 DATA)*

Susan A. Tarbell, Richard E. Payne
and Robert G. Walden

Summaries of moored current meter data from one mooring set and retrieved in 1976 near St. Croix by the Woods Hole Oceanographic Institution are presented. The averaged current data are presented as statistics, spectral diagrams, plots of vector and scalar quantities versus time. Horizontal and vertical mooring motion data are also presented.

Prepared for: *Applied Physics Laboratory
of the Johns Hopkins University
under Contract 600651.*

*A COMPILATION OF MOORED CURRENT DATA AND
ASSOCIATED OCEANOGRAPHIC OBSERVATIONS,
VOLUME XIII (1970 MEASUREMENTS)*

Susan A. Tarbell and Ann W. Whitlatch

Summaries of moored current meter and associated hydrostation data collected in 1970 by the Woods Hole Oceanographic Institution are presented. The averaged current data are presented as Statistics, Spectral Diagrams, Vector and Scalar Plots versus Time. The associated hydrostation data are presented as temperature and salinity plotted versus depth.

Prepared for: *ONR Contracts N00014-66-C-0241; NR 083-004 and N00014-76-C-0197; NR 083-400.*

*A COMPILATION OF MOORED CURRENT DATA AND
ASSOCIATED OCEANOGRAPHIC OBSERVATIONS
VOLUME XV (1971 MEASUREMENTS)*

Susan A. Tarbell and Ann W. Whitlatch

Summaries of moored current meter and associated oceanographic data collected in 1971 in the Atlantic and Pacific Oceans by the Woods Hole Oceanographic Institution are presented. The averaged current and wind data are presented as Statistics, Spectral Diagrams, Vector and Scalar Plots versus Time. The associated hydrostation data are presented as temperature and salinity plotted versus depth.

Prepared for: *ONR Contracts N00014-69-A-0200-6006; N00014-67-A-0204-0048;
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NSF Grant GA-28034.*

COS/MOS 850 CURRENT METER REPORT

James R. Valdes

The COS/MOS 850 current meter is a burst sampling instrument designed to measure current speed, direction, and average water temperature. The instrument utilizes the major components of the Geodyne model 850 current meter, with most of the electronics replaced by COS/MOS integrated circuits. This report describes the operation and the maintenance requirements of the COS/MOS instrument.

Prepared for: *ONR Contract N00014-76-C-0197; NR 083-400 and NSF, Office of the International Decade of Ocean Exploration under Grant OCE 75-03962.*

MARINE POLICY and OCEAN MANAGEMENT

MARINE POLICY
AND OCEAN MANAGEMENT PROGRAM

Included in the abstracts submitted by the marine policy group are a number of papers which have been issued as "W.H.O.I. Technical Reports". We have chosen this medium of publication because there are no appropriate published journals that cover the varied subjects addressed by the marine policy group.

Support: *All work reported in the following papers was prepared under the Woods Hole Oceanographic Institution's Marine Policy and Ocean Management Program, which is supported in part by private funds, by a grant from the Pew Memorial Trust, and as part of the Institution's Coherent Sea Grant Program, sponsored by the Office of Sea Grant, Department of Commerce under Grants #04-6-158-44016, #04-6-158-44104 and #04-6-158-44106.*

Additional sources of support for specific papers are noted where appropriate.

FOREIGN POLICY AND INTERNATIONAL LAW CONTROL
NUCLEAR WASTE DISPOSAL AT SEA

David A. Deese

Oceanic and sub-seabed disposal of radioactive waste raises serious political, legal and institutional issues. Many are inherently international in nature. Others can be addressed largely by a single nation. But in all cases it is crucial to assess these issues as quickly as possible for ongoing disposal practices and as early as possible for disposal methods in R&D stage. Such assessment serves at least two vital purposes: it allows us to modify and implement socially and technically acceptable options; and it exhorts us to delay or prevent undesirable practices and proposals.

All past and future sources of radioactivity reaching the oceans and seabed are important for total loading calculations. For present purposes, however, we will focus on two radioactive waste disposal concepts: the possibility for emplacing high-level materials in the deep seabed; and the past and continuing practice of dumping drums of low and medium-level wastes from ships. All past disposal by dumping has been based on a philosophy of dilution and dispersal in the oceans. But most future concepts, especially in the United States, depend on containment by natural and engineered barriers until the radionuclides have decayed to innocuous levels. Disposal by containment presents management problems which are distinct from those raised by dilution and dispersal methods. Use of the seabed to contain and isolate even high-level materials may fall under a new international legal and institutional framework.

Published in: *Proceedings, American Nuclear Society, Annual Meeting, 1977.*

GOVERNING THE DEEP SEABED

David A. Deese

Decisions on nuclear energy development worldwide are increasingly driven by social rather than scientific issues. This seems to hold particularly well for radioactive waste management. Subseabed disposal of high-level waste could well follow this trend. It presents a complex web of national and international political, legal, institutional and social issues.

Yet some solution to the high-level disposal problem must be developed, including a way to deal with wastes from an increasing number of countries which are unlikely to have local options. And sub-seabed disposal - in areas beyond national jurisdictions - could offer some important opportunities for

international cooperation on nuclear waste management, and perhaps also on nuclear non-proliferation.

Published in: *Atomic Energy Law Journal, spring, 1977.*

SEABED EMPLACEMENT AND POLITICAL REALITY

David A. Deese

No assessment of a sub-seabed option for the disposal of high-level radioactive wastes would be complete without an analysis of the parallel political, legal, and institutional implications of such a concept. These considerations could prove to be at least as complex as the scientific endeavors. The path to a sub-seabed option divides in several directions through a thicket of conflicting national and international interests. Which way the United States might ultimately decide to turn would be largely dictated by the extent to which the country decided it must rely on a sub-seabed option for future nuclear waste disposal.

Where do we stand at present on the national and international paths toward a sub-seabed option? We can say that the option is scientifically and technically plausible, but that it could turn out to be unworkable from a legal and political point of view. On the other hand, the national and international mechanisms exist that could, if judiciously set in motion, make it the most viable of all alternatives.

Published in: *Oceanis, 20(1), Winter, 1977.*

THE SCIENTIST AS EXPERT WITNESS: WHY LAWYERS
AND SCIENTISTS CAN'T TALK TO EACH OTHER

James M. Friedman

This essay analyzes the difficulties presented when scientific testimony is introduced at trial. The ambivalent attitude of the law towards the expert witness is explained. The cultural problems which can result when a scientist is asked to perform legal functions in a legal forum are also discussed.

Published in: *The New Lawyer, March, 1977.*

MATHEMATICAL MODELS AS COMMUNICATION
STRATEGIES IN THE PUBLIC POLICY PROCESS

John E. Kelly

Mathematical models of complex systems have become an increasingly common part of the decision-making process in many areas of public policy. In three related areas - energy, food, and the environment - the complexity of the problems and the ramifications of policy alternatives are so great that mathematical models are necessary to deal with the vast quantity of

data and the dense network of interconnections among variables. Given the large capacity of current computing machines, these models can provide the decision-maker with the consequences of a policy option in a matter of minutes, and thus offer a useful tool in the decision-making process.

However, mathematical models are necessarily built on a set of assumptions about the system being modeled. These assumptions so structure the model as to limit the set of policy alternatives and bias the simulation of the system given the selection of a policy option. As a decision-making tool, models thus have their limits, and in some cases, their dangers. When the decision-maker is unaware of the assumptions embedded in the model, his use of the model amounts to abdication of his authority to the model-builder. When models are used to defend a policy before the public, the limitations of the model can threaten the democratic process through which the full range of options is considered.

In recent environmental disputes, such as those over the siting of nuclear power plants, models have been used to convince decision-makers and the public that a proposed course of action would do no harm to the environment. These models, usually built by the utilities, are based on a set of assumptions which are debatable on scientific and technical grounds. When the models are presented to the public, informed opponents of the industry challenge the proposed course of action by challenging the assumptions of the model. Public discussion of policy alternatives is thus focused on the assumptions of the model being used to defend the selected option rather than on the goals and objectives of public policy in the area.

Though in this sense models create a context for debate, they also foreclose discussion of the more basic issues involved. Rather than being introduced after a course of action has been selected and used to defend that action, models should be built before goals and objectives have been established. If the system were modeled before these initial choices, discussion would be focused on the more basic issues involved.

Furthermore, the model-building process should continue as goals and objectives are established. The assumptions of the resulting model can then reflect those goals chosen by the designated decision-makers and the public rather than the bias of the model-builder. In addition, a model built in this fashion can provide decision-makers with a set of alternative courses of action to achieve their goals and can simulate the enactment of a wide variety of

policy options rather than the limited set favored by the model-builder.

In the end as in the beginning of the decision-making process, however, a model can be nothing more than a tool, and its utility is as much determined by the people who use it as by those who build it. No model can make decisions about goals and objectives nor select the optimal policy alternative. These are man's role in the system. He must also be constantly alert to the possibility that the model is leading him astray rather than toward his goals. It is this feedback function which Norbert Wiener, father of cybernetics, referred to as the "human use of human beings".

This paper deals with the communications aspect of the decision-making process as it is shaped by the use of mathematical models. Examples from three areas - food, energy, and the environment - illustrate the process. Models are shown to be less useful in providing concrete data than in demonstrating the dynamics of the system and creating a context for discussion of the issue. In this sense models are communication strategies or devices rather than pictures of the real world, and their successful employment is testimony to the truism that he who establishes the terms of the argument has the advantage.

THE FISHERY CONSERVATION AND MANAGEMENT ACT OF 1976; ORGANIZATIONAL STRUCTURE AND CONCEPTUAL FRAMEWORK

John E. Kelly

The Fishery Conservation and Management Act of 1976 (FCMA) extended United States jurisdiction from 12 to 200 miles and initiated a comprehensive national programme of fishery management. The programme is based on the concepts of maximum sustainable yield (MSY) and optimum yield (OY), and the Act establishes a new organizational structure in the form of eight Regional Fishery Management Councils to carry out the programme. The conceptual framework and the organizational structure envisaged in the Act are both complex. The relationship between them is not easily determined without some theoretical context based on the study of framework analysis as applied to organizations. Generally, the degree of congruity between the formal and the perceived organizational structure and conceptual frameworks determines the effectiveness of an organization.

Published in: *Marine Policy*, 2(1), Jan. 1978.

*CHANGES IN THE SHOREBIRD FAUNA OF A SMALL
TROPICAL ESTUARY FOLLOWING HABITAT ALTERATION:
BIOLOGICAL AND POLITICAL IMPACTS
OF ENVIRONMENTAL RESTORATION*

Arnold L. Lum

Numbers of shorebirds visiting the Paiko Lagoon Wildlife Sanctuary, a small tropical estuary located on Oahu, Hawaii, are compared prior to and following environmental restoration of the lagoon. An attempt is made to examine both the biological impacts and policy implications of the project. The biological results indicate that shorebird abundance did not increase following restoration. On the other hand, public perceptions regarding the ecological value of the lagoon suggest that in spite of a lack of biological benefit to shorebirds, the lagoon was perceived by the public, particularly local residents, as being of increased ecological value because it had been aesthetically improved. The discussion focuses on the interplay between scientific and non-scientific factors in natural resource decision-making.

In press: *Environmental Management*.

TOWARDS A POLICY IN LATIN AMERICA

Francisco J. Palacio

The purpose of this paper is to stress the need for the adoption in Latin America of comprehensive policies which consider the ocean as an integral and important part of the process of development. The ability to adopt and implement such policies is directly related to the marine scientific capability of the country and to national awareness of ocean affairs. Effective development of these two aspects can only come about through national commitments. In most Latin American countries such commitments are unsatisfactory or lacking.

The positions adopted in the United Nations Law of the Sea Conference by Latin American countries are not equivalent to marine policy definitions. Jurisdictional pronouncements have been essentially the translation of Latin American fears from resource exploitation by foreign interests before the countries develop themselves the necessary scientific and technological capability. In spite of the contributions by Latin American jurists to the Law of the Sea, the only joint declaration that has had the power of an international treaty is the 1952 Declaration of Santiago when Peru, Chile and Ecuador claimed territorial seas of at least 200 miles. The Declarations of Montevideo (1970) Lima (1970) and Santo Domingo (1972) are simply statements of adherence to principles. In addition, only Haiti, Mexico, Dominican Republic

and Venezuela have both signed and ratified the four Conventions derived from the 1958 Geneva Conference (Garcia-Amador, 1976).

CAPE COD'S FISHERY COOPERATIVES

Susan B. Peterson

The Cape towns of Chatham and Provincetown both have fishery cooperatives which were established under the 1934 Fishery Cooperative Marketing Act. Although technically the same because of the structure provided by that legislation, there are marked differences between the two coops - differences in fishing methods, marketing and species sought as well as differences among the men and their vessels. This paper explores those differences.

Published in: *The Cape Naturalist*, 6(3), Winter, 1977.

THE EVOLUTION OF FRESH FISH PROCESSING

Susan B. Peterson

Fresh fish processing in New England expanded from small, family-operated enterprises to large, industrialized enterprises during the years from 1900-1960. Since that time, a combination of scarcity of fish supply and high operating costs, part of which can be attributed to unionized labor, has caused a bifurcation in the industry. Businesses which continued to expand changed their product from fresh fish to frozen fish, while other businesses reduced their numbers of employees and their expectations about volume in order to continue processing fresh fish. This paper outlines the alternatives available to fresh fish buyers and describes some ways in which they dealt with variability in supply.

Paper prepared for: "Fishermen and Mariners Symposium at the Northeastern Anthropological Meetings", Providence R.I. 1977.

*THE MASSACHUSETTS LOBSTER FISHERY:
MODEL LEGISLATION AND MANAGEMENT PLANS*

Susan B. Peterson and James M. Friedman

In March of 1976 the Massachusetts Lobstermen's Association (MLA) requested help in the preparation of limited effort legislation. During the previous year the General Court of Massachusetts had directed that the Director of Marine Fisheries should not issue more than 1300 licenses annually for the coastal lobster fishery, a ruling included in an amendment to Chapter 130 of the General Laws. Section 2 of the amendment further directed that the Division of Marine Fisheries develop a system for issuing permits and limiting the amount of gear used in coastal lobstering by 8 December, 1976. In December 1976

the Division of Marine Fisheries requested a one-year continuation of the moratorium. The MLA members felt that they had a special interest in the state's action, and thus wanted as much help as possible in preparing legislation affecting their livelihood. While we agreed with MLA that they needed advice on managing the coastal lobster fishery, we could not provide them with information tailored specifically to their needs. Rather, we agreed to prepare model legislation with a number of management alternatives directed at conserving the lobster on behalf of all citizens of Massachusetts.

FISHING GEAR ADAPTABILITY - THE USES OF DATA

Susan B. Peterson and Ann Martin

Data collected by the National Marine Fisheries Service relating to United States fishing vessels is useful to regional management councils in making decisions about United States fishing effort and capacity. Data on types of fishing gear used in New England, selected from the NMFS files, is analyzed here to suggest relationships between specific ports and types of gear, and to enumerate the number of vessels showing gear adaptability - use of more than one type of gear during 1976 - and their port relationships and probable gear combinations. The percentage of multiple-gear vessels in New England has grown from 7% in 1964 to 19% in 1976, and the authors propose a detailed study to form a basis for projections about the quantity of vessels which will change from single to multiple gear in the future, based on both the probability and the capability of vessels to change gear.

Additional support: NMFS Contract
No. 03-6-043035165.

THE NEW ENGLAND INDUSTRY: A BASIS FOR MANAGEMENT

Susan B. Peterson and Leah J. Smith

Fish and fishermen appear to be in a serious decline in New England. The haddock are overfished, inshore herring stocks are depleted, yellowtail flounder and lobster are scarce. The popular image is of grizzled fishermen, their boats chipped, scarred, old-fashioned hulks of wood tied up two and three abreast along the rotting wharves and piers of New England depressed port towns. In this research project we wanted to determine the state of the New England fishing industry and to propose acceptable methods for the management of the fishery.

During our early discussions with fishing industry people we mentioned that we were interested in limited effort programs as they might be applied to New England fishermen. We carefully, and probably tediously, explained

the "theory of limited effort" and we were generally thought to be daft. We were told we had things backwards - that the fishing industry needed more fish, more men, more boats - and that the way to accomplish this was to get a 200-mile fishing limit and kick the foreigners out.

One of these wishes has come true - in the spring of 1976, Public Law 94-265 established a 200-mile fishing zone off the United States, with regional management councils to make management plans and allocate the resources first to United States fishermen, with surpluses to foreign fishermen.

THE FAILURE OF SUCCESS IN FISHERIES MANAGEMENT

Courtland L. Smith

Law of the Sea negotiations and The Fishery Conservation and Management Act of 1976 create new options in fisheries management. Historical analysis of two major management programs in the United States of America, Columbia River chinook salmon (*Oncorhynchus tshawytscha*) and Pacific halibut (*Hippoglossus stenolepis*), shows two unresolved management problems. One is the innovativeness of fishermen in seeking ways to improve their harvests. The other is changing social priorities that are largely unpredictable and outside the control of fisheries managers. A method for analysis of patterning associated with management goals is illustrated. Since the general management goals are harvest improvement and more predictability, measures are used which show the adequacy of fit and reduction in variability between actual and predicted management outcomes.

Published in: *Environmental Management*
1(3):239-247, Springer-Verlag N.Y.
Inc. 1977.

GRADUATE STUDENTS

GRADUATE STUDENTS

(Abstracts of theses submitted in 1977 by graduates of the Woods Hole Oceanographic Institution Doctoral Degree Program and the Massachusetts Institute of Technology/Woods Hole Oceanographic Institution Joint Program in Oceanography/Oceanographic Engineering.) Papers authored or co-authored by graduate students are included in the departmental sections. Students are indicated by an asterisk in the Author Index.

GRADUATE STUDENTS

THE CHEMISTRY, BIOLOGY, AND VERTICAL FLUX
OF OCEANIC PARTICULATE MATTER

James Kenneth Branson Bishop

Submitted to the Massachusetts Institute of Technology-Woods Hole Oceanographic Institution Joint Program in Oceanography on January 13, 1977, in partial fulfillment of the requirements for the degree of Doctor of Science.

Abstract

Particulate matter samples, split into $<1\ \mu\text{m}$, $1-53\ \mu\text{m}$, and $>53\ \mu\text{m}$ size fractions have been obtained using a Large Volume *in situ* Filtration System (LVFS) during the *Southlant* Expedition, R/V *Chain* 115. Profiles to 400 m are reported for LVFS Stations 2 and 4-8. Stations 4, 5, and 8 (Southeast Atlantic, coastal waters near Walvis Bay region and Cape Town, high biological productivity); Stations 6 and 2 (Southeast Atlantic, Walvis Bay region and equatorial Atlantic, moderate productivity; and Station 7 (Southeast Atlantic, edge of central gyre, low productivity) formed a suite of samples for the study of the chemical, biological, morphological distributions and of the vertical mass flux of particulate matter as a function of biological productivity.

All samples were analysed for Na, K, Mg, Ca, carbonate, opal, Sr, C and N and those from Station 2 were further analysed for P, Fe, $\delta^{13}\text{C}$, ^{7}Be , ^{214}Bi , ^{214}Pb , (^{226}Ra), ^{210}Po , and ^{210}Pb . Biological distributions of Acantharia, dinoflagellates, coccolithophorids, Foraminifera, diatoms, silicoflagellates, Radiolaria, and tintinnids were made by light microscopy (LM) and augmented by scanning electron microscopy (SEM). Size and morphological distributions of the $53\ \mu\text{m}$ particles, especially Foraminifera, Acantharia, fecal pellets, and fecal matter have been determined by LM and SEM.

The particle distributions were controlled at all stations by processes of production, consumption, fragmentation, and aggregation. Maxima in organism abundance and particulate mass were generally coincident. They were found nearest the surface when the mixed layer was absent or poorly developed, and at the base of the mixed layer at the other stations.

Organism vertical distributions showed consistent features: Acantharia, and dinoflagellates were always nearest the surface; Foraminifera and diatoms were shallower than or at the base of the mixed layer; Radiolaria and tintinnids were found in the upper thermocline.

Coccolithophorids and diatoms were the dominant sources of particulate carbonate and opal in the near-surface waters, coccoliths and diatom fragments, deeper.

Features of the distributions of particulate matter attributed to the feeding activities of zooplankton were: strong concentration gradients in organisms, mass, and organic matter; enrichment of the $>53\ \mu\text{m}$ fraction with coccoliths causing the steady decrease in $>53\ \mu\text{m}$ Si/carbonate ratio with depth from values as high as 45 to values near 1.0 at 400 m; the decrease in organic content with depth from values near 100% near the surface to 50 and 60% at 400 m for the <53 and $>53\ \mu\text{m}$ size fractions; the fragmentation of most material below 100 m; and the production of fecal pellets and fecal matter which are carriers of fine material to the sea floor.

Other features were: the nearly constant organic C/N ratios ($7.3 \pm 0.5\alpha$) found for the $1-53\ \mu\text{m}$ fractions at Stations 4, 5, 6, and 8 compared with the steady increase observed at Stations 2 and 7 with depth; particulate carbon was rather uniformly distributed below 200 m with concentrations showing a mild reflection of surface productivity; the $<1\ \mu\text{m}$ C/N and $\delta^{13}\text{C}$ values are lower and lighter than the $1-53\ \mu\text{m}$ fraction, perhaps indicative of the presence of marine bacteria; the Ca/carbonate ratios in most samples significantly exceeded 1.0, values as high as 2.5 were observed at Station 8; the xs Ca and K have shallow regenerative cycles and contrast with Mg which is bound to a refractory component of organic matter; based on an organic C/ xs Ca ratio of 100-200:1 for surface samples, the cycling of xs Ca was calculated to be $1-2 \times 10^{13}\ \text{mol/cm}^2/\text{y}$ compared with the production of carbonate, $7 \pm 2 \times 10^{13}\ \text{mol/cm}^2/\text{y}$.

Chemical effects noted were: organic matter had both binding capabilities and ion-exchange capacity for major and minor ions present in sea-water. Acantharia (SrSO_4) dissolve most significantly below 200 m at Station 2.

The vertical mass fluxes through 400 m at Stations 2, 5, 6, and 7 were calculated from size distributions measured in $1\ \text{m}^3$ in seawater for Foraminifera, fecal pellets, and fecal matter. Two flux models were used together with Junge distributions for these calculations. Fecal matter and Foraminifera transported most mass at Stations 2 and 5 where the fluxes were between 2 and 3, and 5 and 6 $\text{gm/cm}^2/1000\text{y}$ respectively; fecal matter, Foraminifera, and fecal pellets contributed equally to the $.9-1.3\ \text{gm/cm}^2/1000\text{y}$ flux at Station 6; and fecal pellets and Foraminifera were the carriers of $0.1-0.3\ \text{gm/cm}^2/1000\text{y}$ to the sea floor. Corresponding chemical fluxes of organic carbon, carbonate, and opal were: 80-90, 11-24, and $\sim 10\ \text{mmol/cm}^2/1000\text{y}$ at Station 5; 15-20, 2.7-5.0 and 1.7-2.5

mmol/cm²/1000y at Station 6; 1-4, 0.6-1.5, and 0.1-0.3 mmol/cm²/1000y at Station 7, and 40-65, 4.6-7.4, and 4.9-7.9 mmol/cm²/1000y at Station 2. Over 90% of the organic matter produced in the euphotic zone is recycled in the upper 400 m. The efficiency is nearly 99% in areas of low productivity; the organic to carbonate carbon ratios are highest at locations where the flux is greatest as are the Si/carbonate ratios. Besides carbonate, opal, celestite, and other mineral phases, organic matter may be a significant carrier of minor and trace elements to the deep ocean.

Supported by: ONR Contract N00014-75-CO291 and Doherty Foundation.

QUASIGEOSTROPHIC FLOWS AND TURBULENCE IN A ROTATING HOMOGENEOUS FLUID

Alain Colin de Verdiere

Submitted to the Department of Physical Oceanography on August 1977 in partial fulfillment of the requirements for the Degree of Doctor of Science from Massachusetts Institute of Technology and Woods Hole Oceanographic Institution.

Abstract

Stimulated by new evidence from both "*in situ*" oceanic observations and results from numerical modelling, a laboratory study of quasigeostrophic flow and turbulence in a rotating homogeneous fluid has been undertaken. Two-dimensional turbulence, driven by a uniform distribution of sources and sinks which oscillate in time, can be fairly well reproduced in this context. Inertial time scales are about ten times smaller than Ekman spinup time, and typical Reynolds numbers read 2000. The observations emphasize the spectral tendency of the energy containing eddies. The case of no topography is first discussed. In steadily forced turbulence, it is observed that the energy containing scale is significantly larger than the forcing scale. In the decaying stage the red cascade is observed and rates of interaction are measured. Theoretical arguments for both behaviors are presented; the former concerning the forced turbulence case is believed to be new.

The forcing is next applied over various large scale topographies, modelling the geophysical beta effect. The polar beta plane geometry preserves the above spectral characteristics but at the same time introduces anisotropy into the flow pattern. A broad westward mean flow develops in the north and is surrounded by a belt of cyclones lying on its southward side. The calculated second-order Eulerian mean flows induced by steadily and uniformly forced Rossby waves in a long zonal channel, exhibit much of the same momentum distribution in the inertial regime. In contrast, the "sliced cylinder" geometry which possesses no closed geostrophic

contours drastically modifies the above picture. Both mean flow production and a large scale tendency for the eddies are inhibited. The geographical distribution of the eddy intensities and scales is now wildly inhomogeneous.

The second aspect of this work is a study of the interaction of Rossby waves with mean flows. A zonally travelling, forced wave is generated near the southern boundary of a polar beta plane. Due to energy radiation in the free interior and (or) potential vorticity mixing by the finite amplitude waves, a westward zonal flow develops. The effect of the mean flow upon the forced steady waves is to weaken the anticyclones and intensify the cyclones. Pressure time series reveal a growth of harmonics and general spectral broadening as the waves travel freely inwards, suggesting active nonlinear interactions. An experimental test of Rhines' (1977) potential vorticity mixing theory is also presented at free latitudes. The decay period when the driving is suppressed shows that a net transfer from the waves to the mean flow kinetic energy occurs. Connection with hydrodynamic stability theory is discussed.

Interaction of Rossby waves with an externally generated westward mean flow allows one to make a controlled study of the critical layer problem. For small amplitude waves, the mean flow is accelerated in the entire region between the forcing and the critical latitude which acts as a wall for mean wave momentum. In nonlinear runs the steady profile of the westward flow indicates that an accelerating force is acting everywhere, revealing the increasing transmission of wave momentum through the critical layer. At the same time, pressure measurements near the critical point show considerable fine structure developing over a long time scale.

The third part deals with steady isolated source-sink flows in the sliced cylinder geometry. The response of the fluid to a meridionally oriented steady dipole extends exclusively westward of the forcing. The viscously balanced solutions are discussed and relevance to oceanic abyssal circulation is emphasized. With strong driving, the combination of a cyclone to the north and an anticyclone to the south is absolutely stable although the reverse configuration is not. A connection with a certain class of free steady, isolated, inertial solutions developed recently by Stern (1976) is made.

Supported by: Joint Program in Oceanography, Massachusetts Institute of Technology and the Woods Hole Oceanographic Institution; NSF Grant OCE75-21 674 and ONR Contract N00014-74-CO262-NR-083-004.

*THE KINEMATICS AND DYNAMICS OF THE NEW ENGLAND
CONTINENTAL SHELF AND SHELF/SLOPE FRONT*

Charles Noel Flagg

Submitted to the Massachusetts Institute of Technology - Woods Hole Oceanographic Institution Joint Program in Oceanography on April 19, 1977, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Abstract

A 37 day long field program was carried out in March 1974 on the New England continental shelf break to study the current and hydrographic structure and variability on the shelf and in the shelf/slope front. A second experiment was conducted in the shelf break region for one week in January 1975 to study frontal exchange processes.

The mean currents during the March 1974 experiment all had a westward alongshore component, increasing in magnitude progressing offshore from ~ 5 cm/sec to a maximum at the nearshore edge of the shelf/slope front of between 10 and 20 cm/sec, and decreasing in magnitude with depth. The current structure was such that the velocity vector rotated clockwise with depth in the shelf waters inside the front. The mean alongshore transport of shelf water was on the order of 0.4 Sverdrups through a cross-shelf transect south of Block Island. About 30% of the transport occurred in the wedge-shaped region offshore of the 100 m isobath and inshore of the front. Comparison of the observed mean currents with those predicted by the steady frictional boundary layer model of Csanady (1976) indicates that the model captures most of the essential features of the shelf circulation.

The low frequency currents contain approximately 30% of the total current variance. An empirical orthogonal modal analysis indicates that for low frequency alongshore motions the whole shelf together with the water above the front moves as a unit and that the on-offshore currents are characterized by opposing flows at surface and bottom. The alongshore wind stress component is the dominant forcing term for these low frequency motions and for the subsurface pressure field as well. For motion with periods longer than 33 hours, the time derivative term in the cross-shelf momentum balance is comparable with the Coriolis term while the advective terms are 2 and 10 times smaller, on the average.

The semi-diurnal tide is barotropic over the shelf with current magnitudes that increase almost by a factor of two between the shelf break and the inshore mooring 79 km shoreward. At the shelf break one-dimensional continuity gives the correct relation between the surface tide and the semi-diurnal currents. The semi-diurnal tide is clockwise polarized. The

diurnal tide is baroclinic, increasing somewhat toward the bottom, is less clockwise polarized than the semi-diurnal, and has tidal ellipses aligned with the isobaths. The diurnal tidal energy decreases toward shore.

Inertial energy in the frontal zone is equal to the semi-diurnal tidal energy near the surface. The inertial energy decreases with depth and is an order of magnitude smaller further on the shelf. The inertial oscillations are shown to be highly correlated with the wind stress record, arising and decaying on a time scale of three to four days. The inertial oscillations are shown to be preferentially forced by wind stress events that have a large amount of clockwise energy at near inertial periods.

The frontal zone is shown to be in near geostrophic balance with an anticipated vertical shear across the front of the order of 5 to 8 cm/sec. Thus, there is a wedge-shaped region of velocity deficit that is confined directly under the front and above ~ 200 m. Outside of this region the velocity is alongshore to the west. Low frequency motion of the front is shown to exist on time scales from 3 to 10 days although the complete nature of the motions is not known. An oscillation of the front about its mid-depth position at periods of 3 1/2 to 4 days was caused initially by an eastward wind stress event forcing the front offshore near surface and onshore along the bottom. This was accompanied by large temperature oscillations near the bottom at midshelf and current oscillations confined to those current meters near the front.

The internal wave band is most energetic in the center of the front, is about half as energetic above the front where it is subject to variations associated with the wind stress, and is smaller and nearly constant below the front. The internal wave energy decreases shoreward reflecting the decreasing stratification shoreward of the wintertime hydrography. Linear internal wave theory seems to break down in the conditions of the frontal zone.

A stability analysis of the front to small perturbations is carried out by extending the model of Margules frontal stability of Orlandi (1968) to include the steep bottom topography of the shelf break region. The study covers the parameter range pertinent to the New England continental shelf break region and indicates that the front is indeed unstable; however, the associated growth rates are so slow that baroclinic instability does not seem to be a viable explanation for the observed frontal motions. Application of the theory to the nearly flat topography of the shelf itself shows that the front would be at least 20 times more unstable there suggesting that the front would migrate offshore to the shelf break region until a

stable equilibrium was established between frictional dissipation and the instabilities.

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*GEOLOGIC EFFECTS OF THE GULF STREAM SYSTEM
IN THE NORTH AMERICAN BASIN*

Edward P. Laine

Submitted to the Massachusetts Institute of Technology-Woods Hole Oceanographic Institution Joint Program in Oceanography on July 20, 1977, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Abstract

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 geologic record than previous interpretations based strictly on the influence of the classic 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 southward flowing Western Boundary Undercurrent and the northward flowing deep flow of the Gulf Stream System led to the formation of a pair of outer ridge deposits; respectively the Hudson and Gulf Stream Outer Ridges, 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

Hudson Outer Ridge dammed a similar series of turbidites behind its landward flank. 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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*DATA ADAPTIVE VELOCITY/DEPTH SPECTRA ESTIMATION
IN SEISMIC WIDE ANGLE REFLECTION ANALYSIS*

Steven John Leverette

Submitted to the Department of Ocean Engineering on July 1, 1977 in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Abstract

In studying the earth with reflection seismics, one of the major unknowns is the velocity structure of the medium. Techniques used to determine the velocity structure commonly involve multi-channel arrays which measure the spatial as well as the time structure of the returning signals. The application of a data adaptive technique, the Maximum Likelihood Method, to the problem of estimating seismic velocities is described. The peculiar problems of this application are identified and investigated. The windowing of short duration signals is shown to be an important consideration, and the statistics of the MLM estimator for a single observation of the data set are presented. The adaptive estimator is applied to an ideal covariance matrix, to simulated data, and to field data. The results show the MLM velocity/depth estimator to be a valuable tool in seismic analysis, and the windowing and statistical results should have general applications in a variety of fields.

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*STUDIES ON THE METABOLISM OF TRYPTOPHAN IN
Klebsiella aerogenes: Enzymology and Regulation*

Charles Gregory Paris

Submitted to the Massachusetts Institute of Technology/Woods Hole Oceanographic Institution Joint Program in Biological Oceanography on the 23rd of August, 1977, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Klebsiella aerogenes can utilize aromatic amino acids as sole source of nitrogen, but not

as sole source of carbon. *Klebsiella* abstracts the α -amino group of these compounds by transamination, and excretes the arylpyruvate into the medium, where it is used no further. When tryptophan is utilized as sole source of nitrogen by *Klebsiella*, indolepyruvate is excreted into the medium, where it polymerizes non-enzymatically to form a brick-red pigment.

There are at least four separate aminotransferase (AAT) activities found in *Klebsiella*. One activity (AAT-I) appears to be solely responsible for the aminotransferase reaction necessary for the growth of *Klebsiella* on tryptophan, as its loss by mutation (*tut*⁻) prevents the growth of the cell on this and other aromatic amino acids. None of the other AAT activities in the cell can substitute for AAT-I in this regard.

AAT-I has been purified to homogeneity and characterized. It is a dimer composed of subunits of equal molecular weight (42,000 daltons). This enzyme exhibits multiple isoactivity bands when assayed by an amino-transferase activity stain in native polyacrylamide gels subjected to electrophoresis. The patterns exhibited by these isoactivity bands change during the purification; the molecular basis of these activity bands is unknown. AAT-I has a moderate affinity for tryptophan and phenylalanine (K_m values of 0.60 mM and 80 μ M, respectively), and similar affinities for α -ketoglutarate and oxaloacetate (K_m values of 2.08 mM and 0.12 mM, respectively). It shows high affinity for phenylpyruvate (K_m of 20 μ M), but no affinity for aspartate.

Of the other AAT activities found in *Klebsiella*, one is tentatively identified as a tyrosine-repressible aromatic aminotransferase (analogous to the *tyrB* product in *E. coli*), and another (AAT-IV) as a nonrepressible aromatic aminotransferase (analogous to the *aspC* product in *E. coli*). AAT-IV has been partially purified and characterized. It has a low affinity for tryptophan and phenylalanine (K_m values of 60 mM and 83 mM, respectively), a moderate affinity for phenylpyruvate (K_m of 1.6 mM), and high affinity for α -ketoglutarate (K_m of 30 μ M) and aspartate.

Tryptophan-dependent pigment formation in *Klebsiella* is positively controlled by the intracellular levels of the enzyme, glutamine synthetase. Bulk AAT activity in the cell, however, varies less than 2-fold in response to 10-fold or greater changes in the levels of glutamine synthetase. AAT-I, assayed in activity-stained native polyacrylamide gels, exhibits changes in the isoactivity band patterns which appear to be mediated by glutamine synthetase.

A tryptophan permease activity is shown to exist in *Klebsiella*; tryptophan-dependent pro-

duction of indolepyruvate is assayed in intact, resting whole cell suspensions. The expression of this activity does not require induction by tryptophan. The derepression of this tryptophan permease activity, up to 10-fold, is mediated solely by the levels of glutamine synthetase in the cell.

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THE MARINE GEOCHEMISTRY OF METHANE

Mary Isabelle Scranton

Submitted to the Joint Oceanographic Committee in the Earth Sciences, Massachusetts Institute of Technology and Woods Hole Oceanographic Institution on August 10, 1977, in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

Abstract

In the highly productive coastal surface waters near Walvis Bay, methane is present in concentrations considerably above those which would be predicted from solubility equilibrium with the atmosphere. A one-dimensional diffusive model and a one-dimensional horizontal advection diffusion model were used to describe the methane distribution. Evaluation of the model fits to the data suggests that both advective supply of methane-rich coastal waters and *in situ* biological methane production are important sources for the mixed layer methane excess. The complexity of the hydrographic regime near Walvis Bay makes it impossible to make a quantitative estimate of the rate of methane production.

In the less productive Murray-Wilkinson Basin in the Gulf of Maine, a mixed layer methane excess is also observed. Methane concentrations are closely correlated with hydrographic parameters and the source of methane at a middepth maximum appears to be the highly anoxic sediments in the adjoining Franklin Basin. Diffusion of methane from the middepth maximum is probably adequate to maintain the surface methane excess against loss across the air-sea interface.

Coastal waters are frequently enriched in methane, and it has been shown that advective supply of these methane-rich waters may be a significant source of methane for the mixed layer near the coast. Thus the widespread occurrence of a methane maximum at the base of the mixed layer in the open ocean, coupled with surface waters typically 30-70% supersaturated with respect to solubility equilibrium, suggests that advective supply of methane might be an important methane source for the open ocean as well. However, a study of the western subtropical Atlantic shows that advective transport can probably supply

only a fraction of the methane present in the maximum. Also the loss of methane across the air-sea interface was observed to be twenty times greater than the flux from the maximum. Thus *in situ* methane production must be very important to the open ocean methane distribution.

A series of phytoplankton culture experiments demonstrated that cultures of both *Coccolithus huxleyi* and *Thalassiosira pseudonana* produce trace amounts of methane during logarithmic growth. (Because the cultures are highly oxygenated, anaerobic methane bacteria can be neglected as methane sources. However heterotrophic bacteria cannot be excluded as possible sources of methane to the cultures.) After three algal generations, the rate of methane increase closely parallels the growth curve suggesting that the methane is in fact coming from the algae. A methane production rate of 2×10^{-10} nmole methane/viable cell/hr was calculated from the data. This rate is three to four orders of magnitude slower than the rates of oxygen consumption and glutamate and glucose uptake measured by other workers for algae and bacteria. The methane production rate calculated from the culture experiments is the correct order of magnitude to account for the methane production occurring in the open ocean.

Methane is present in quite low concentrations in the deep ocean. By calculating water mass ages from GEOSSECS and other data, it is possible to estimate methane consumption rates in the deep sea. Methane consumption is rapid at first (probably greater than 0.06 nmole/l/yr). At depth consumption appears extremely slow. This may be due to the fact that the methane concentrations in the deep sea are so low that methane oxidizing bacteria cannot use methane as a substrate, or due to reduced metabolic activity in the bacteria at the high pressures and low temperatures of the sea floor.

Methane is present in very high concentrations in anoxic basins, indicating that methanogenic bacteria are active. However, near the anoxic-oxic interface in both the Black Sea and the Cariaco Trench a one-dimensional advection diffusion model predicts that methane consumption is occurring in the anoxic zone. In the Black Sea the methane depletion may be indicative of the presence of rapid methane oxidation near the Bosphorus overflow. However in the Cariaco Trench the validity of such an explanation is difficult to evaluate since the overflow process is so poorly understood. A box model for the Trench has been developed which incorporates time dependence and supply of chemical species to the water from the sediments at all depths in the Trench. This model can explain the silica and sulfide data quite well, but methane depletion near the interface, relative to the model predictions, still occurs.

Thus either anaerobic methane oxidation or decreased methane production in the sediments must be hypothesized.

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OBSERVATIONS OF INTERACTION BETWEEN THE INTERNAL WAVEFIELD AND LOW FREQUENCY FLOWS IN THE NORTH ATLANTIC

Barry Raymond Ruddick

Submitted to the Massachusetts Institute of Technology - Woods Hole Oceanographic Institution Joint Program in Oceanography on April 11, 1977, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Abstract

A total of four moorings from POLYMODE Array I and II were analyzed in an investigation of internal wavefield-mean flow interactions. In particular, evidence for wave-mean flow interaction was sought by searching for time correlations between the wavefield vertically-acting Reynolds stress (estimated using the temperature and velocity records), and the mean shear. No significant stress-shear correlations were found at the less energetic moorings, ($\bar{u} \lesssim 10 \text{ cm s}^{-1}$), indicating that the magnitude of the eddy viscosity was under $200 \text{ cm}^2/\text{sec}$, with the sign of the energy transfer uncertain. This is considerably below the $0(4500 \text{ cm}^2/\text{sec})$ predicted by Müller (1976). An extensive error analysis indicates that the large wave stress predicted by the theory should have been clearly observable under the conditions of measurement.

Theoretical computations indicate that the wavefield "basic state" may not be independent of the mean flow as assumed by Müller, but can actually be modified by large-scale vertical shear and still remain in equilibrium. In that case, the wavefield does not exchange momentum with a large-scale vertical shear flow, and, excepting critical layer effects, a small vertical eddy viscosity is to be expected. Using the Garrett-Munk (1975) model internal wave spectrum, estimates were made of the maximum momentum flux (stress) expected to be lost to critical layer absorption. Stress was found to increase almost linearly with the velocity difference across the shear zone, corresponding to a vertical eddy viscosity of $\sim 100 \text{ cm}^2 \text{ s}^{-1}$. Stresses indicative of this effect were not observed in the data.

The only significantly non-zero stress correlations were found at the more energetic moorings ($\bar{u} \sim 25 \text{ cm s}^{-1}$). Associated with the 600 m mean velocity and the shear at the thermocline were a positively correlated stress at 600 m, and a negatively correlated stress at

1000 m. These stress correlations were most clearly observable in the frequency range corresponding to one- to eight-hour wave periods. The internal wavefield kinetic and potential energy were modulated by the mean flow at both levels, increasing by a factor of two with a factor of ten in the mean flow. The observed stress correlations and energy level changes were found to be inconsistent with ideas of a strictly local eddy viscosity, in which the spectrum of waves is only slightly modified by the shear. When Doppler effects in the temperature equation used to estimate vertical velocity were considered, the observations of stress and energy changes were found to be consistent with generation of short (0.4 to 3 km) internal waves at the level of maximum shear, about 800 m. The intensity of the generated waves increases with the shear, resulting in an effective vertical eddy viscosity (based on the main thermocline shear) of about $+100 \text{ cm}^2 \text{ s}^{-1}$. The stresses were not observable at the 1500 m level, indicating that the waves were absorbed within 500 m of vertical travel.

The tendency for internal wave currents to be horizontally anisotropic in the presence of a mean current was investigated. Using the Garrett-Munk (1975) model internal wave spectrum, it was found that critical layer absorption cannot induce anisotropies as large as observed. A mechanical noise problem was found to be the cause of large anisotropies measured with Geodyne 850 current meters. It could not be decided, however, whether or not the A.M.F. Vector Averaging Current Meter is able to satisfactorily remove the noise with its averaging scheme.

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ACCURACY BOUNDS FOR NORMAL-INCIDENCE ACOUSTIC STRUCTURE ESTIMATION

Kenneth B. Threlkult

Submitted to the Massachusetts Institute of Technology/Woods Hole Oceanographic Institution Joint Committee for Oceanographic Engineering, on 2 August, 1977, in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

Abstract

Determination of the structure of a medium from normal-incidence acoustic reflection data is a basic problem in fields as diverse as medical technology and the earth sciences; this research examines the accuracy with which quantitative structure estimates can be made from noise-corrupted measurements of reflected energy. Two classes of simple physical models, which exclude geometrical spreading and attenuation, are developed: one in which the properties of the medium change continuously with

depth, and one in which they change discretely. Given these reasonable models, estimation accuracy is studied by computing a statistical lower bound on estimator performance, the Cramer-Rao bound, for three cases of interest. (1) The bound is computed for the estimation of unknown, non-random reflection coefficients in a medium containing only discrete reflectors; special attention is given to the one- and two-reflector situations. The bound's ability to predict estimator performance is demonstrated, as is the inadequacy of a particular ad-hoc estimation method based on the Wiener-Levinson algorithm of stochastic filtering theory. (2) The bound is developed for estimation in a continuous medium whose structure (acoustic impedance, for example) parameterized by a set of unknown, non-random coefficients, and for which the reflection response may be computed in closed form. The problem of estimating the parameters of a single, isogradients velocity layer of known depth is studied in detail. It is demonstrated that one can identify the parameters of such a layer from normal-incidence measurements given an appropriate source and experiment geometry. (3) A unique extension of some known results in random process estimation is used to derive a pointwise bound for estimation in a continuous medium whose structure (reflection coefficient density) is a random process. Again we give special consideration to the problem of identifying a single isolated layer structure. We demonstrate that for a weakly scattering structure, estimation accuracy is independent of the mean or nominal structure.

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