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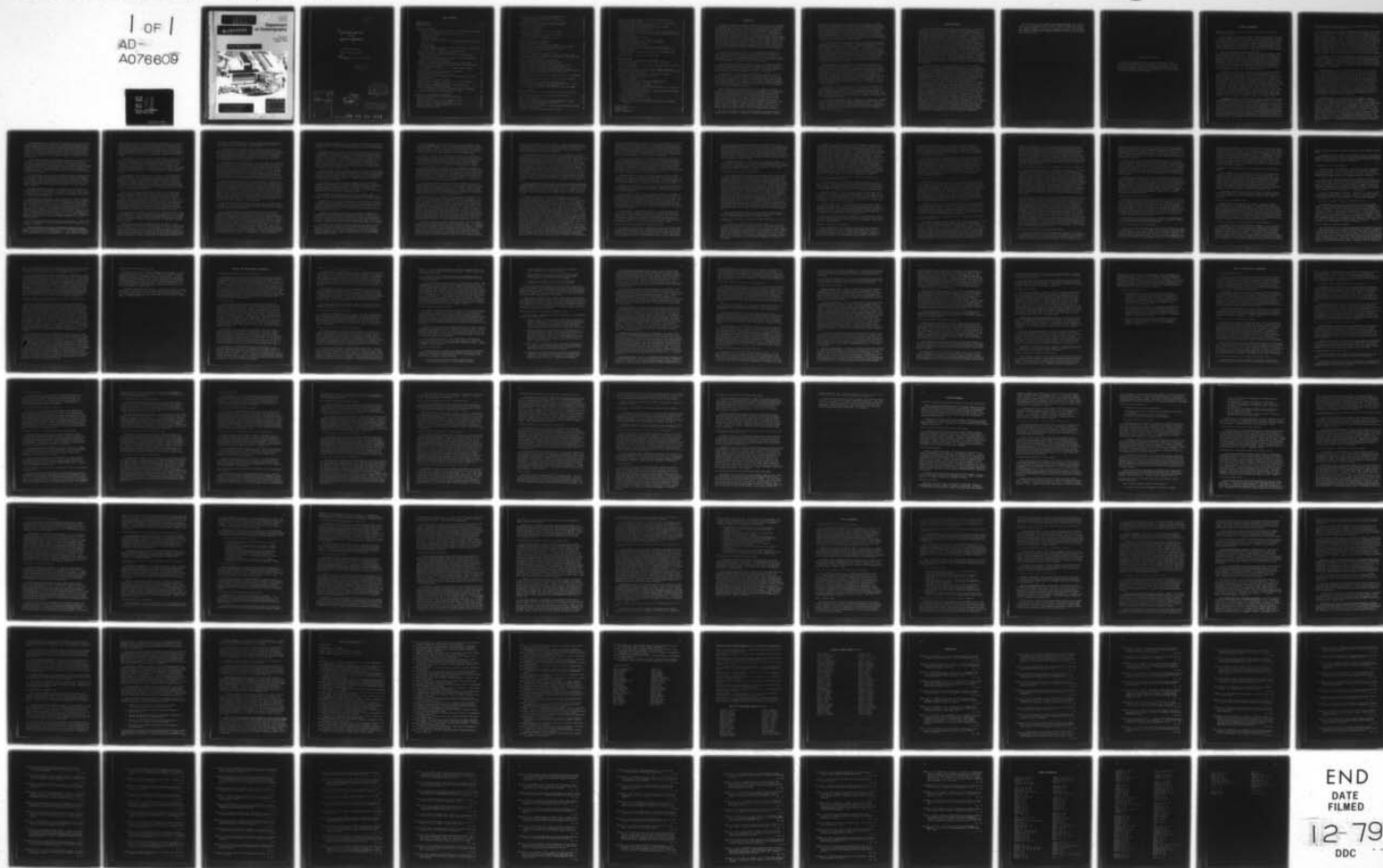
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Abstract

INTRODUCTION

Comprehensive teaching and research programs are conducted at the Department of Oceanography, University of Washington, by a diverse group of faculty, staff, students, and support personnel. The research program is presently comprised of more than 150 projects covering a broad range of oceanographic investigations and has annual expenditures in excess of six million dollars. These investigations range from one-person individual research projects to participation in multidisciplinary, multiuniversity projects, such as the Coastal Upwelling Ecosystems Analysis program (CUEA), the Deep Ocean Mining Environmental Study (DOMES), the Global Atlantic Tropical Experiment (GATE), the International Program of Ocean Drilling (IPOD) supported by the Deep Sea Drilling Project (DSDP), the International Southern Ocean Studies (ISOS), the Manganese Nodule Program (MANOP), the Outer Continental Shelf Environmental Assessment Program (OCSEAP), the Joint U.S.-U.S.S.R. Mid Ocean Dynamics Experiment (POLYMODE), the Processes and Resources of the Bering Sea Shelf program (PROBES), and the Rivera Ocean Seismic Experiment (ROSE).

Abstract

The research is supported primarily by funds from federal agencies. The major sources of funding during 1977-78 were the National Science Foundation (45%), National Oceanic and Atmospheric Administration (22%), Office of Naval Research (15%), and the Department of Energy (12%). The remaining support was derived from the U.S. Army Corps of Engineers, U.S. Air Force, various state and local government agencies, and from private organizations.

The research program provides substantial support for teaching via a large assortment of facilities and projects that are available for student research. In 1977-78, 32 Master of Science degrees were awarded, six students achieved the Ph.D. degree, and 74 Bachelor's degrees were awarded. There are presently 96 graduate students and 200 undergraduates enrolled in the Department.

During the past two years, several administrative changes have occurred. Dr. D. James Baker, Jr. became Chairman of the Department, March 26, 1979. Dr. Maurice Rattray, Jr. returned to full-time teaching and research after serving as chairman from 1968-1978. Dr. Richard W. Sternberg was named Acting Chairman for the period September 1978 - March 1979. Dr. George C. Anderson became Associate Chairman for Research in September 1977, replacing Dr. Francis A. Richards, and Dr. Dean A. McManus became Associate Chairman for Instruction in September 1978, replacing Dr. Richard W. Sternberg.

Both the educational and research aspects of the department have been enhanced by the addition of the following new faculty members: Jack W. Anderson, Affiliate Associate Professor; Edward T. Baker, Research Associate; Nikolas I. Christensen, Adjunct Professor; Allan Clarke, Research Associate; Michael R. Davey, Research Associate; John R. Delaney, Acting Assistant Professor; Eric Firing, Research Associate; Jan Garmany, Research Associate; Donald W. Hood, Senior Research Associate; Gregory Holloway, Research Assistant Professor; Michael C. Macaulay, Research Associate, Harold O. Mofjeld, Affiliate Assistant Professor; Arthur R.M. Nowell, Research Assistant Professor; Pedro Ripa, Research Associate; Thomas B. Sanford, Research Professor; William R. Schell, Adjunct Associate Professor; Colin Y. Shen, Research Associate, Richard J. Stewart, Adjunct Associate Professor; Richard L. Temkin, Research Associate.

The faculty is augmented through joint appointments of personnel with the Applied Physics Laboratory, the Geophysics Program, the Atmospheric Sciences

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Department, the Department of Geological Sciences, the College of Fisheries, the Division of Marine Resources, and the Institute of Marine Studies of the University. Additional research opportunities for the department are provided by associations with the Pacific Marine Environmental Laboratory of NOAA and the U.S. Geological Survey. Several PMEL and USGS personnel are affiliate faculty members, and numerous joint research projects are being conducted. Cooperative arrangements with other governmental agencies, i.e., the National Marine Fisheries Service, the National Ocean Survey, the U.S. Coast Guard, the U.S. Navy, the U.S. Army Corps of Engineers, and the Washington State Department of Ecology also extend the research opportunities.

In July 1977 the "Joint Institute for Study of the Atmosphere and Ocean" (JISAO) was established via a "Memorandum of Understanding between the Environmental Research Laboratories of the National Oceanic and Atmospheric Administration and the University of Washington." The purposes of JISAO are: (1) to increase the effectiveness of oceanographic and atmospheric research of mutual interest to the ERL (in particular, but not limited to, Pacific Marine Environmental Laboratory) and the relevant units of the University by promoting close multidisciplinary collaboration among scientists associated with these two institutions and visiting scientists; (2) to provide a center at which scientists working on problems of mutual interest may come together; (3) to stimulate the training of scientists in the many disciplines involved in the oceanographic and atmospheric sciences.

The department has been designated by the Department of Energy as the "Coordinating Office for Oceanographic Programs in Pacific Northwest Coastal Waters." A contract has been awarded to Dr. George C. Anderson to provide coordination services for Department of Energy supported oceanographic research in universities in the Pacific Northwest region. A Pacific Northwest Paleomagnetic Consortium has been formed among the University of Washington, the University of Alaska, Oregon State University, and Western Washington University. The consortium will provide access to sophisticated equipment necessary for research in paleomagnetism and rock magnetism. The equipment will be housed in the Department of Oceanography, University of Washington. The consortium is funded by the National Science Foundation, with additional support from the Graduate School.

Several major research journals are edited by departmental faculty. Dr. D. James Baker, Jr. is co-editor of *Dynamics of Atmospheres and Oceans*; Dr. Michael Gregg and Dr. Ronald T. Merrill are associate editors of *Journal of Physical Oceanography* and *Journal of Geophysical Research*, respectively. Dr. Dean A. McManus is editor of *Marine Geology* and Dr. Francis A. Richards is the editor of *Deep-Sea Research*. Dr. Dora P. Henry is a member of the latter journal's Editorial Advisory Board.

Well-equipped teaching and research laboratories are augmented by a research fleet consisting of the 209-foot general oceanographic research vessel, the *Thomas G. Thompson*, two 65-foot vessels, the *Hoh* and the *Onar*, the 50-foot *Kestrel*, and various small craft. The department has recently submitted a proposal to the National Science Foundation for construction and assignment of a coastal zone research ship.

MARINE OPERATIONS

In 1977, the R/V *T.G. Thompson* conducted biological studies off the Washington coast in early January before proceeding south to the waters off California. From late January through March, an environmental assessment program including water column studies and benthic investigations was carried out in the Southern California Bight by Science Applications, Inc. under contract to the Bureau of Land Management. The work was followed by a geological cruise off southern California under sponsorship of the University of Southern California and a chemistry cruise off San Francisco Bay by Moss Landing Marine Laboratories. The *Thompson* returned to local waters in April where biological and geological studies were carried out off the Washington coast. From mid May to late June, the *Thompson* participated in a NORPAX Anomaly Dynamics Study. The purpose was to determine geostrophic currents from hydrographic data and to provide a comparison with currents determined from satellite-tracked drift buoys. From early July to mid August, a number of cruises were carried out in local waters. These included chemical studies of anoxic environments in Saanich Inlet, studies of hydrocarbons, sediment dynamics, and plankton off the Washington coast, and investigations of nutrient diagenesis in sediments of Cascadia Basin, off Washington. In mid August, the *Thompson* returned to California for an additional month of work in the Southern California Bight. The remaining time was devoted to investigations of nutrient diagenesis and sediment dynamics off Washington.

During 1978, the R/V *T.G. Thompson* spent much of the year in distant waters. In early January, the *Thompson* departed Seattle for work off Central America. En route, a week of investigation concerning the poleward undercurrent was carried out off Washington and Oregon. A month-long study of nutrient diagenesis in marine sediments was carried out in the Guatemala Basin, where ancillary projects on nutrient and trace metals in the water column, as well as hydrographic studies, were conducted. The following biological and chemistry cruises off Mexico involved deployments of moored sediment trap arrays as part of a study of flux of organic matter through the water column and pump casts to define features of the pycnocline and oxygen minimum layer. On the transit back to Seattle in March, a marine refraction experiment was conducted off the northern California coast and sediment dynamics studies were carried out off Washington. In early April, the *Thompson* departed Seattle for the Bering Sea to begin work for PROBES (Processes and Resources of the Bering Sea Shelf), a multidisciplinary, multiinstitutional ecosystem investigation. The three and one half month PROBES cruise was divided into several legs involving physical oceanography, nutrient chemistry, and food chain dynamics. After leaving the Bering Sea, the *Thompson* proceeded to station Papa in the Gulf of Alaska for a study of phytoplankton-zooplankton interactions and particulate matter flux through the water column. The ship returned to Seattle in early August before carrying out a number of programs off the Washington coast in the latter part of the year. These programs included collections of cores on the continental shelf; an investigation of the Pacific Northwest subduction zone including deployment of ocean bottom seismometers and a deep-towed seismic array; and firing rift refraction line shots at these instruments; chemical and physiological investigations of the phytoplankton and zooplankton population studies; and a November cruise to study the poleward undercurrent.

The R/V *Hoh* and R/V *Onar* primarily were engaged throughout 1977 and 1978 in short cruises in Puget Sound, the Straits of Georgia, Knight Inlet, Saanich Inlet, and Lake Washington. These cruises covered a wide spectrum of biological, chemical, geological, and physical oceanography projects. The R/V *Kestrel* was utilized in various student training cruises and participated in the Knight Inlet estuarine study.

RESEARCH ACTIVITIES REPORT

This report contains summaries of the projects currently being carried out in the Department of Oceanography. The faculty, staff, and students associated with each research project are identified at the end of the project summary; square brackets indicate the students who participated in the research. Inquiries may be addressed to the faculty members or to the Associate Chairman for Research.

BIOLOGICAL OCEANOGRAPHY

Mechanisms of Transfer of Energy and Biomass in Coastal Marine Ecosystems of the Pacific Northwest

This biological research program stresses studies of mechanisms of transfer of energy and biomass in coastal ecosystems in the Pacific Northwest. The objectives of the research include a better understanding of the processes governing the communities of organisms in the water column, on the seabed, and in the surf zone. Field and laboratory phytoplankton studies emphasize physiological processes and adaptations to environmental stress. A quantitative model of phytoplankton production has been constructed. Also included are studies of the zooplankton, benthos, and the previously much neglected surf zone. (G.C. Anderson)

Analyses of oceanographic field data (1974-1977):

Since 1974 field investigations on the temporal and spatial variations of phytoplankton abundance and productivity, nutrient concentrations, irradiance, and density structure have been conducted in the waters off the coast of Washington. Multivariate statistical methods are being used to analyze a data set which is comprised of 22,500 data points generated from measurements of 12 variables -- temperature, salinity, sigma-T, oxygen concentration, oxygen saturation, phosphate, silicate, nitrate, nitrite, ammonium, chlorophyll *a*, and phaeopigments -- from each of 10-15 depths at the approximately 150 stations that were occupied during six cruises: July 1974, March-April 1975, July 1975, October 1975, September 1976, January 1977 (totaling 1875 depths).

The results of factor analysis indicate that five underlying and presumably causal factors are responsible for 98.9% of the observed variability in the measured variables. These factors are identified through their loadings on the measured variables and through maps of the factor scores. The factor analysis not only summarizes the field data, but also identifies major oceanographic mechanisms that control biological oceanographic processes in Pacific Northwest coastal waters. The five factors are, in order of decreasing contribution to the total variance in the data, deep-water contribution (including upwelling), fresh-water input, a phytoplankton-grazing couple, a stratification factor, and an excretion-low light couple. Building on the results of the factor analysis, samples from all depths and geographic locations occupied on six cruises between 1974 and 1977 can be classified. Samples are grouped according to their similarities on the factor scores for the five factors noted above. Maps produced from these groups show sharply contrasting trends for the winter versus summer seasons. (Perry, Jumars, G.C. Anderson, Campbell, W.K. Peterson, Postel)

Phytoplankton studies: The dynamics and the species composition of phytoplankton assemblages in the coastal zone are influenced directly by the physical environment and indirectly through the physiological responses of the resident phytoplankton to the environment. The factor and cluster analyses provide information on dominant environmental processes, while experimental studies of ^{14}C -carbon and ^{15}N -nitrogen assimilation provide data on phytoplankton physiological responses and rates of production. Data on species composition are being analyzed using a cluster analysis to classify homologous groups within each cruise and, for combined data from several cruises, to look for seasonal patterns and patterns associated with different water masses, as indicated by the factor and cluster analyses. Autoradiographic analysis of individual phytoplankton cells

is being conducted to provide information on relative metabolic activities and viabilities among and within species groups.

The variability in cell activity, expressed as photosynthetic incorporation of ^{14}C , was examined by autoradiographic analysis of phytoplankton cells. *Dunaliella euehlora* was grown at 21°C in continuous light in a nutrient-sufficient batch culture where $\mu_{\text{max}} = 1.05 \text{ dy}^{-1}$, and in three nitrogen-limited chemostat cultures where $\mu = 0.95 \text{ dy}^{-1}$, 0.58 dy^{-1} , and 0.38 dy^{-1} . During the exponential phase of growth in the batch culture, the individual cells showed some variation in the density of labeling. However, all cells were heavily labeled, indicating that all cells were viable and active. The results of the continuous culture where $\mu = 0.95 \text{ dy}^{-1}$ were similar to those from the batch culture. In contrast, at the lower growth rates, the cells could be divided easily into three groups -- cells with medium, light, or no labeling. No diurnal variation in activity was revealed in 24-hour experiments. These results indicate that these are cells with no observable metabolic activity and that there is a range of activities within a chemostat-grown population at steady state. (Perry, Xypolyta, Campbell)

Nitrification is microbial transformation that is important in coastal waters off the Washington coast. A fluorescent antibody assay has been developed to allow direct enumeration of *Nitrosococcus oceanus*, a marine ammonium-oxidizing bacterium, in seawater. This immunofluorescent assay is a very sensitive method, capable of detecting a few cells l^{-1} . Specificity of the assay has been demonstrated in the laboratory and the technique is also being successfully applied to field samples. (Perry [Ward])

Zooplankton studies: Field observations, theoretical studies (Jamart et al., 1977), the results of factor analysis (see p. 1), and the investigations on chlorophyll degradation products (see p. 3) indicate that grazing and nutrient regeneration by zooplankton play significant roles in structuring the distribution and abundance of phytoplankton, particularly during the summer months. Our approach toward obtaining a quantitative understanding of phytoplankton-zooplankton interactions in this region is a combined field and laboratory program; simulation models, and a conceptual model of the effect of species size on annual turnover rates continue to provide a theoretical context for the experimental investigations. The objectives of the field program are to quantify natural grazing rates of microzooplankton and larger zooplankton and to determine the abundance and composition of the zooplankton assemblages. Laboratory studies focus on feeding and growth rates of the naupliar stages of copepods and on developing new experimental methods for assessing natural grazing pressure in the field.

Planktonic grazers play an important role in phytoplankton dynamics. Planktonic filter-feeding copepods are the dominant component of the net zooplankton. Their youngest developmental stages, the nauplii, are also major constituents of the microzooplankton and consequently may be an extremely important source of grazing mortality to the phytoplankton. Our understanding therefore of the pelagic community off the Washington coast depends, in large degree, on knowledge of the role of naupliar stages of copepods -- how they feed, grow, regenerate nutrients, and serve as a source of food. Yet the role of these microzooplankters cannot be predicted at present from what we know of larger forms. The matter is further complicated by the interaction of food size and animal size in respect to feeding rates and growth efficiency. The goal of this project is to begin to assess the role of copepod nauplii in phytoplankton dynamics by determining their feeding and growth rates in laboratory cultures.

Feeding and growth rates of the last four naupliar stages of *Calanus pacificus* as a function of food concentration at 12°C have been determined. Near-optimum growth was observed at food concentrations as low as 43-49 μg carbon liter⁻¹. Under optimum food conditions, the gross growth efficiency was about 33% and the assimilation efficiency, assuming a respiration rate extrapolated from observations on young copepodids, was about 62%. These data are incorporated into a preliminary carbon budget which represents feeding, defecation, respiration, and growth rates of the naupliar stages of *C. pacificus*. (Frost [Harker, Yen])

Current studies emphasize the background grazing pressure exerted by microzooplankton, e.g., ciliates and copepod nauplii, which are too small to be identified or manipulated individually at sea or to be physically separated from phytoplankton with routine collection methods. Primary production estimates are complicated by the fact that one cannot avoid including the effects of these consumers in routine ¹⁴C uptake experiments. Therefore, we are attempting to determine grazing rates of microzooplankton using a dilution procedure and specific metabolic inhibitors.

The grazing impact and size-selective feeding of larger zooplankton species are being investigated by more conventional experiments using a multichannel Coulter Counter. These experiments are conducted in conjunction with sampling for zooplankton biomass and species composition and with sediment trap studies that use phaeophorbide content from captured zooplankton fecal material as an alternate means of assessing zooplankton grazing impact on the phytoplankton. (Landry [Hassett]).

Chlorophyll degradation products: Chlorophyll degradation products, primarily phaeophorbide *a*, are produced by the passage of the chlorophyll *a* molecule through the gut of a herbivore. In the marine environment, these products are found in finely dispersed particulate matter, in zooplankton fecal pellets, and incorporated within sediments.

Phaeophorbide *a* has been used as a tag to partition the origin of sedimenting carbon in Dabob Bay, Washington, during an annual cycle. Annual primary production is approximately 30 $\text{mgC cm}^{-2} \text{yr}^{-1}$. The sedimentation rate of carbon onto the bottom is 7 $\text{mg cm}^{-2} \text{yr}^{-1}$ or about 23% of the level of primary production: 2.3 $\text{mgC cm}^{-2} \text{yr}^{-1}$ is directly related to grazing activity on phytoplankton. About 79% of the flux occurs during the spring and fall blooms. The remainder of the sedimentary carbon derives from other compartments of the food web, for example, zooplankton and the organic detritus pools. Sedimentation of carbon onto the seafloor, ranging from 10 $\mu\text{g cm}^{-2} \text{d}^{-1}$ in the late winter to 38 $\mu\text{g cm}^{-2} \text{d}^{-1}$ early in the fall, is not as variable as phaeophorbide sedimentation. Phaeophorbide varies from .6 $\mu\text{m cm}^{-2} \text{d}^{-1}$ during the spring to .04 $\mu\text{g cm}^{-2} \text{d}^{-1}$ during the winter.

Short-term experiments have been carried out on the Washington shelf. Preliminary results show that the level of phaeophorbide flux is similar to that in Dabob Bay. (Lorenzen)

Sensitivity analysis of a model of phytoplankton growth in the Pacific Ocean: In a recent publication (Jamart et. al., 1977), a numerical two-dimensional (time and depth) model of phytoplankton growth and nutrient distribution off the Northwestern U.S. coast was described. The model consists of coupled

integro-partial differential equations expressing conservation of chlorophyll *a*, nitrate, and ammonium. The relevant physical and biological processes are represented by conventional functions and parameters. The system is "closed" by specification of grazing pressure and light intensity. A long-term simulation over spring and summer months (for convenience, called the "standard run") represents well the main features of observed chemical data and biological variables, including the formation and deepening of a subsurface chlorophyll maximum.

Subsequently, a sensitivity analysis of the system was carried out by comparing the "standard run" with the results of twenty numerical experiments, in each of which a single function or parameter in the model is modified. The formation of the subsurface chlorophyll maximum is simulated, more or less realistically, in all experiments. Moreover, the results suggest that the chlorophyll distribution adjusts in time and depth so as to optimize the transfer of carbon to secondary producers. The level of the carbon output is determined mainly by the resources available to the primary producers. (Winter, Banse [Jamart])

Benthos studies: Two approaches are being used in our investigations of biomass and energy transfer in the benthos -- component process studies and long-term monitoring. Field experiments and theories derived from them are being used iteratively to investigate the component processes of dispersal, recruitment, and deposit feeding. The net effects of these and other community processes are being monitored empirically via a long-term sampling program. In parallel with these two approaches run such taxonomic efforts as are necessary to provide unambiguous identification of the important species (e.g., the target of deposit-feeding experiments).

Notable progress has been made during the last year in the recruitment aspects of our work. Spatial auto-correlative studies of both natural and defaunated sediments at Skagit mudflat (northern Puget Sound) clearly showed two spatial scales to be of particular importance: organismal patches of < 1 cm and statistically significant periodicity of the patches of about 10 cm. Manipulations revealed that the patches are likely due to the very small-scale modifications of the benthic boundary layer by tube builders. Recruitment is enhanced in the immediate vicinity of initial colonizing tube builders; this effect has been duplicated by substituting artificial, tube-like structures (< 1 mm diam.) for the initial colonists. The 10-cm periodicity in recruitment apparently is set up by ripples in the bed or by the currents over them.

Recruitment thus is sensitive to small-scale (< 1 mm) and mesoscale (10 cm) geophysical effects. This finding has serious implications for the use of larval settling containers or cages in monitoring or experimenting with the recruitment process. Both types of apparatus affect the ambient flow regime on the scales shown to be important; container or cage effects are to be expected, requiring careful controls.

Through further measurements and manipulations, the effects of these apparent geophysical forcings on the recruitment process will be quantified more fully and larger spatial scales also will be examined. Biological interactions, expected on the smallest scale (i.e., those of individuals and their feeding areas), will also be monitored and manipulated. Both laboratory and field experiments will be used, the former to create carefully controlled conditions in the benthic boundary and the latter to ensure that the results apply realistically

to the field. The continuing goal is to reveal and quantify the factors that control recruitment in the field and to develop methods whereby recruitment can be altered in a predictable way. (Jumars [Eckman])

A model of selective feeding by deposit feeders has been developed; it utilizes parameters such as particle size, particle energy content, gut passage time, and a time-specific assimilation efficiency term to predict the particle size a deposit feeder should ingest to maximize its net rate of energy gain. Gut passage time and time-specific assimilation efficiency are the variables with especially dramatic effects on optimal particle selection coefficients and the subsequent net rate of energy gain.

The assumptions underlying the model are now being tested. The assumption that assimilation efficiency is independent of particle characteristics, such as size and energy content, implies both constant gut-passage time and constant time-specific assimilation efficiency for different particle types. However, there is increasing evidence that these implications may not be valid for some species (Lopez and Levinton 1978; Self and Jumars 1978). The rates at which various particle types are passed through deposit feeders' guts are also of interest for two related reasons. The passage determines when particles will again be available for recolonization by microorganisms (Lopez et al. 1977) and which paths they will follow in the sedimentary cycle (Self and Jumars 1978).

Therefore gut passage rates and particle selection will be emphasized in testing both the assumptions and the predictions of the model. Exotic particles of carefully controlled characteristics will be used in field experiments because of the complexity of natural sediments. Several types of deposit feeders, rather than a single species as in many previous studies, will be used in particle selection experiments as different groups of deposit feeders (polychaetes, molluscs, crustaceans, etc.) undoubtedly differ in particle collection costs and digestion rates. These parameters, which are included in the model, influence optimal selection strategies. Determining the feeding responses of a variety of deposit feeders, therefore, should provide quantitative and qualitative insight into phenomena, such as size-selective feeding, that have been reported frequently but are poorly understood. (Jumars [Taghon])

Investigations of the benthic fauna in the main basin of Puget Sound are continuing; 33 collections were made between February 1963 and November 1978 in this long-term study of stability. All of the bivalve mollusks and the dominant polychaete species have been identified.

The overriding feature noted in this study is the constancy of species composition among the polychaetes and bivalves during the 15-year study. Although the total number of species/sample ($0.1m^2$) varies between sampling periods, as discussed below, there have been no important additions to the basic species list presented by Lie (1968) after a two year study (1963-64). Major changes have occurred, however, in the abundance of the two numerically dominant species within this community. The overwhelming dominant at the outset was the tellinid clam *Macoma carlottensis* (greater than 100 specimens/sample) and the dominance continued with over 50 specimens/sample through 1967 (samples were not collected in 1968). In 1969 and early 1970, however, this species was found in negligible numbers (5 or 0 specimens/sample). At the same time, a heretofore minor polychaete species, *Pectinaria californiensis*, became the numerical dominant (up to 100 specimens/sample). The dominance of *P. californiensis* was

apparently short-lived (samples were not collected in 1971-1972) as in 1973 only a few were present (less than 10 specimens/sample). In late 1970, there was a resurgence of *M. carlottensis*, continuing with greater than 230 specimens/sample in 1977.

The character of any (negative) relationship between these two species is not understood. The dramatic increase in the abundance of *M. carlottensis* in late 1970 when *P. californiensis* was near or at its own peak abundance suggests that the earlier decline of the former was not necessarily in response to the increase of the polychaete. Coincident with the decrease in numbers of *P. californiensis* was a gradual increase in the abundance of a smaller polychaete species, *Ampahrete acutifrons* (up to 40 specimens/sample in November 1978.) This polychaete was recorded, but in very low numbers, in the earlier samples. Again, no relationship to changes in abundance of either *M. carlottensis* or *P. californiensis* can be inferred as yet.

Another apparent change in the benthic fauna has been a more-or-less steady increase in the number of polychaete species/sample, from about 10 species/sample in 1969-73 to about 20 species/sample. Verification of the initial finding and a comparison with pre-1969 data cannot be done, however, until identification of minor species of polychaetes is completed. (Kisker; Nichols, U.S. Geological Survey, Menlo Park, California)

The preparation of the second and last volume of keys for the benthic polychaetes and archiannelids of the Oregon Biogeographic Province (between Pt. Conception and Dixon Entrance) continues. Approximately 260 species will be included; however, a considerable number of taxonomic revisions as well as checking of many doubtful records have had to be made. In the last year, four families have been treated with the following results:

Acrocirridae: Two new species of *Acrocirrus*, *A. columbianus* and *A. occipitalis*, are described from shallow water of southern British Columbia. They belong to the group of North Pacific species with compound neurosetae throughout.

Ampharetidae: Morphological and distributional observations on 11 of the 19 ampharetid species and subspecies recorded from British Columbia and Washington are presented. *Hobsonia* new genus and *Sosanopsis hesslei* new species are described, and remarks made on the generic diagnosis of *Sosanopsis*. A new species of *Samytha* and two species of *Ampharete* are newly recorded for the Oregon Biogeographic Province.

Terebellidae: A new genus, *Betapista*, is described. An examination of type material of many species of the family made it possible to improve the diagnoses of two genera, redescribe one species, and add to the description of nine other species, some of which are new records for the Oregon Biogeographic Province. Four other new records were also recorded, and records of two species previously thought to be represented in the Province were shown to be erroneous.

Sabellidae: Fourteen northeast Pacific species were critically examined. Based on type material, additions to the descriptions of nine species are provided. *Eudistyla* is revised and a new species, *E. catharinae*, described. The diagnostic characters of *Sabella* are discussed, and one of its subgenera, *Demonax*, is emended. Three species are newly recorded for the Oregon Biogeographic Province. (Banse)

Surf-zone studies: Large standing stocks of surf zone diatoms ("brown water") are a characteristic feature of the surf along sandy beaches of Washington and Oregon, covering a distance of approximately 325 miles of coastline, during all seasons of the year. The diatom species comprising the blooms at the present time are *Chaetoceros armatus* T. West, a filamentous centric diatom, and *Asterionella socialis* Lewin and Norris, a colonial pennate diatom.

Features of the surf diatom species that make them unique and worthy of study include: (1) their occurrence throughout all seasons of the year, attaining their greatest biomass during late autumn, winter, and early spring; (2) their persistence as high biomass from year to year. In fact, the whole ecosystem of this coastal region is of interest because of the great amount of organic material, both plant and animal, that is being produced. (Lewin)

The prolific growth of algal material in turn generates an abundance of marine fauna, in particular the Pacific razor clam (*Siliqua patula* Dixon) which attains its greatest abundance and most rapid growth rate on the beaches where the diatom blooms are most concentrated. The abundance of lipid droplets, siliceous fragments from the frustules of the two surf species, and clay particles (released from the coat surrounding the cellular filaments of *C. armatus*) in the gut contents indicates that surf diatoms, particularly *C. armatus*, are the major contributors to the diet of the razor clam.

To gain an understanding of energy flow and transformation of materials in this unique ecosystem, it is necessary to learn as much as possible about the chemical composition of the dominate species and the rates of important physiological processes. The chemical composition of *C. armatus*, as well as of the clam, has been determined and the contribution of the razor clams to regeneration of ammonium in the surf environment has been investigated. Papers on both projects are in press; the results are summarized below.

Field collections of *C. armatus* have a large inorganic component, due to the presence of clay minerals (illite and montmorillonite) surrounding the cell chains: 63% of the dry weight of the material collected in November was inorganic. The organic fraction was composed of 67.6% lipid, 29.7% protein, and 1.3% carbohydrate. Cultured cells also were high in protein and lipid and low in carbohydrate. Traces of chitin found in field samples were probably a contaminant, since chitin was absent from cultured cells. Protein constituted 47% and lipid 42% of the dry weight of razor clam tissue. The fatty acid distribution in the diatom lipid resembled that previously reported for other diatom species; similarly the fatty acid distribution in the clam lipid was similar to that previously reported for other bivalve molluscs. Clam fatty acids differed in chain length and degree of saturation from those extracted from its food source, indicating an active fatty acid metabolism in the clam. (Lewin; C.-H. Chen, Department of Medicine, T. Hruby, Woods Hole Oceanographic Institution)

Studies of the rates of excretion of ammonium by razor clams were commenced in June 1975 and continued into February 1977 (a 20-month period). Our aim was to perform short-term experiments in the field in order to insure that conditions were as close as possible to those prevailing in the natural habitat at the time of the study. There was no previous experimental work that might serve as a guide as to how the clams might best be maintained in a healthy physiological condition during an experimental period lasting over several hours. For this particular study, each clam was allowed to bury itself into a measured amount of

sediment held within a large plastic container. A similar experimental setup, minus the clam, served as a control for each experiment. This approach afforded us the opportunity to determine at the same time whether or not there was a significant ammonium excretion due to the presence of some of the smaller faunal species within the sandy beach community.

Excretion rates of all nutrients likely to be regenerated in sufficient quantities to affect surf diatom growth were measured; ammonium appeared to be the most important metabolite. Excretion of ammonium by razor clams far exceeded that by other beach fauna. Statistical evaluation of the data showed that ammonium excretion rates were positively correlated with shell length, but no correlation between ammonium excretion rate and water temperature was evident. The lack of correlation may be an artifact or may represent some degree of seasonal acclimation of the species to temperature. Weight-specific ammonium excretion rates were negatively related to clam size indicating a possibly large (and unknown) contribution of regenerated ammonium by smaller clams in their first year of growth. (Smaller clams were rarely captured during this study.) The presence of high clam densities not only in the surf region but also subtidally plus the potentially greater weight-specific ammonium excretion rates of smaller clams indicate that the regeneration of ammonium could be a significant factor in the nitrogen cycle in the surf environment. (Lewin [Eckman, Ware])

On weight dependence of specific production rates and net growth efficiency of field populations: In ecosystem studies, biological efforts in the field and laboratory often concentrate on dominant species. When it is desirable to have estimates of production rates for other animal species, one commonly chooses an appropriate P/B rate (mean production rate/mean biomass) to apply to the standing stock measurements. Length of life usually has been used for selecting a P/B rate.

Following a suggestion by L. Richie, published data on the quotient of annual production/mean biomass (P/B rate) for populations were used to determine specific production rates (rates per unit biomass). Data for aquatic and terrestrial invertebrates between the sizes of copepods and clams, ranging about 10^5 -fold in body weight upon reaching maturity (W_s , kcal) and about 10^2 -fold in P/B rates, were most plentiful. (Data were few for fish and mammals and scarcer for phytoplankton and protozoa.) W_s is shown to be an efficient and precise estimator (scaling factor) of the annual P/B rate, based on data for 33 invertebrates living at annual mean temperatures between 5° and 20°C . The annual P/B rate declines markedly with W_s according to $P/B = 0.65 W_s^{-0.37}$. The exponent differs from the -0.25 power of comparative physiology, e.g., specific respiration. The observed P/B rates for most of the species fall within 50 to 200% of the predicted values. Most of the variability of the weight-scaled P/B relationship is associated with variability in the ratios of annual production/annual respiration (P/R): for a given W_s , species achieving about half the predicted P/B rates have P/R ratios of about 0.1; those achieving twice the predicted P/B rates have P/R ratios of about 1.0. Apparently, efficient populations (high P per unit R) maintain an elevated biomass but do not attain high annual P/B rates. Age upon reaching maturity contributes some variability, with late-maturing (> 1 yr) species trending toward higher P/B rates. The variability is not significantly correlated with phylogenetic relationships (excepting insects for which the P/B rate might not be weight-dependent), feeding type (trophic level), major habitat, production rate, nor biomass of the populations.

The P/B rates of invertebrates living at annual mean temperatures $\geq 25^\circ$ may be elevated over those of temperate species of the same W_s , while those of polar forms are depressed; the data, however, are insufficient for quantification. The reasons for a single power function governing the weight dependence of P/B rates of temperate invertebrates, the particular exponent, and the low variability of the weight-scaled rate among species from very different phyla and ways of life are unclear; an ecological cause, i.e., mortality, combining with the general size dependence of life processes, is implicated.

On the average, the annual specific mortality equals the P/B rate and hence declines by the same power function of W_s . Very small metazoans (pelagic rotifers, benthic meiofauna) tend to have appreciably lower P/B rates than would be expected from extrapolations of the above relationship for larger invertebrates. A refuge from predation by being small is postulated which may also apply for phytoplankton and possibly nauplii of pelagic copepods. For meiofauna, a power function of weight dependence of P/B rates with average rates 3-5 times below those of the larger invertebrates is suggested. P/B rates of terrestrial soil amoebae also fall onto this line.

The annual P/B rates of fishes and mammals likewise decline by a power function of W_s ; the few available data yield exponents of -0.26 and -0.33, respectively. Ecological reasons are again invoked. The P/B and specific mortality rates of temperate fishes seem to be 4-5 times, and those of mammals 20-25 times, higher than those of temperate invertebrates of the same weight.

Although the starting point was a rather applied question, the interest in, and significance of, the results are the discovery of general patterns for the animal kingdom, and the quantification of specific production and mortality rates. (Banse [Mosher])

Data from papers on energy flow through field populations of temperate invertebrates were also used in an investigation of the annual net growth efficiency (NGE), which is approximated here by $100 P_a / (P_a + R_a)$, P_a and R_a being the annual production and respiration rates of populations per unit area. Published NGE values for 15 temperate invertebrate populations range from 13 to 55%. Contrary to the literature on NGE among species, the dependence of NGE on species size (as body weight at the onset of sexual maturity, W_s) is uncertain although the ranges of P_a and R_a , divided by the mean biomass ($\bar{B}$), approach two orders of magnitude.

The $R_a/\bar{B}$ rates of 13 populations decline with a -0.35 power of W_s rather than the -0.25 power of comparative physiology. A possible reason may be a trend toward larger specimens (relative to W_s or full size) in populations of larger species. Among species, a significant dependence of NGE on W_s is not demonstrable for laboratory populations of unicellular organisms and field populations of mammals so that the cost per unit of production might generally be independent of the rate of production by the population. (Banse)

Physiological Studies of Marine Sulfate Reducing Bacteria

All sulfate reducing bacteria isolated thus far from marine habitats have been gram negative, nonsporulating, progressively motile, vibrios of the genus *Dusulfovibrio*. Optimization of growth media and conditions for these bacteria have been evaluated. While growth generally is best in complex organic media at above ambient temperatures, excellent growth obtains at lower temperatures

in a simple salts solution supplemented with an appropriate carbon source. Growth and respiration rates, ETS activities (see also p. 20), substrate utilization, end product formation, and final yields in terms of both electron donor and acceptor have been monitored over the growth cycle for isolates from Lake Nitinat and Saanich Inlet grown in simple salts supplemented with lactate or pyruvate. Interestingly, pyruvate provides more efficient growth than lactate even though there is a smaller free energy change between substrate and the end-product acetate. Autotrophic growth on hydrogen and carbon dioxide is also being investigated. (Ahmed [S. King])

The characterization of bacteria isolated from anaerobic sediments of Saanich Inlet is in progress. More than forty biochemical tests will be used in this project. The development of a simple, rapid, and optimally effective method for the isolation of anaerobes from marine environments is also being investigated. (Ahmed [V. Johnson, S. King]).

Nitrogen Assimilation in Marine Phytoplankton

Nitrate reductase (NR) and glutamate dehydrogenase (GDH) activities were measured in *Skeletonema costatum* (Grev.) Cleve in ammonium and nitrate limited continuous cultures before and after additions of nitrate and/or ammonium. Comparisons of enzymatic activity with nitrogen uptake and assimilation rates, external and internal nitrate concentrations, and external ammonium concentrations were made in order to assess the roles of NR and GDH in nitrogen assimilation and to determine their suitability as measures of nitrogen assimilation rates. NR activity was induced by internal rather than external nitrate concentrations. Ammonium in the medium reduced NR activity under some environmental conditions, but not others. However, ammonium acted indirectly, perhaps by causing the accumulation of an internal pool of an intermediate of ammonium assimilation. NR activity was found to approximate nitrate assimilation rates during growth limited by the nitrogen supply and under some conditions in the presence of high nitrate and ammonium concentrations in the medium. It is hypothesized that a second nitrate reducing mechanism operates under the environmental conditions which result in poor agreement between NR activities and nitrate assimilation rates. GDH activities were consistently low and constant when compared with ammonium uptake and assimilation rates. Consequently, it is proposed that GDH is not the primary ammonium assimilating enzyme under most environmental conditions and cannot be used as a measure of ammonium assimilation.

The enzymes glutamine synthetase (GS) and glutamate synthase (GOGAT) are currently being measured in several phytoplankton species as an alternate means of measuring ammonium assimilation. (Ahmed [Dortch])

Responses of the Photosynthetic Apparatus of Marine Phytoplankton to Environmental Stress

The chlorophyll content of marine phytoplankton varies in response to environmental parameters (light, nutrients, etc.). This variability raises problems in the application of chlorophyll *a* as an indicator of biomass and as a normalizing parameter for photosynthetic and other metabolic rates. There is, however, a less variable component of total cell chlorophyll: P700, the reaction center chlorophyll of photosystem I. Therefore, an alternative to the current use of chlorophyll *a* in biological oceanography is proposed: measurement of the concentration of this less variable component of total cell chlorophyll.

During the past year both laboratory and field methods of extraction and measurement of components of the photosynthetic unit (PSU) — P700 (reaction-center chlorophyll of photosystem I) and light-harvesting chlorophyll — in marine phytoplankton have been developed. These methods proved to be efficient in isolating and quantifying P700 relative to the more abundant light-harvesting chlorophyll. Our preliminary laboratory experiments show two basic, but not necessarily mutually exclusive, adaptive strategies in response to low light levels; some species apparently respond by increasing the ratio of light-harvesting chlorophyll per PSU while others increase the number of PSUs per cell. Nitrogen limitation, on the other hand, produces opposite changes (decreased size and number of PSUs), again with widely different responses among species. We predict which adaptive strategies will be found in particular oceanographic regimes with distinctly different environmental conditions and phytoplankton dynamics and propose to test these predictions both in analogue laboratory systems and in the field. We suggest that the intrinsic characteristic of the PSU and its plasticity can play a major role in determining patterns of succession and equilibrium composition (if any) of marine phytoplankton assemblages. (Perry, M.C. Larsen, Campbell; R.S. Alberte, University of Chicago)

A Comparative Physiological Study of Marine Diatoms and Dinoflagellates in Relation to Irradiance and Cell Size

Cell division rate, cell protein as an estimate of biomass, and chlorophyll *a* content of five diatom and five dinoflagellate species were measured in batch cultures. Experiments were conducted at six levels of irradiance under both continuous light and a 12L:12D cycle. The algal species were selected to cover three orders of magnitude in cell size and to represent different genera.

The onset of light saturation of growth occurred at similar light levels for species of both groups. The diatoms showed higher light-saturated cell division rates than the dinoflagellates -- the regression of the light-saturated rates against cell size produced two parallel lines, one for each group. Size dependence of the light-saturated growth rate was significant at the 95% level of confidence for both groups of microalgae.

The higher growth rates of the diatoms were paralleled by their higher chlorophyll *a*/protein ratios. It was therefore hypothesized that the higher chlorophyll *a*/biomass of the diatoms reflected high photosynthetic capabilities/biomass which in turn gave rise to their higher growth rates in comparison to the dinoflagellates. This hypothesis was confirmed by photosynthetic rate measurements on two diatom and two dinoflagellate species.

The higher photosynthetic capacities/biomass of the diatoms may be an evolutionary adaptation for utilizing low light and may account for their success during the spring phytoplankton bloom when light is an important limiting factor of growth. (Lewin [Chan])

Taxonomy of North Pacific Nanoplankton

Previous studies have shown that small cells (under 20 μ m in diameter) contribute significantly to both standing stock and primary production in the northeast Pacific. Nearly all previous taxonomic work on collections from this area, however, has been concerned with microplankton from net samples, or with diatoms or coccolithophorids in water samples. For these

reasons, and also because many of the flagellates are poorly preserved in formalin or iodine, the nanoplankton species have remained incompletely known. The purpose of this qualitative study is to differentiate and identify the various species of phytoplankton normally lumped into the categories of "miscellaneous microflagellates" or "naked dinoflagellates" in the enumeration of phytoplankton communities.

Samples that cover a wide geographical range, collected at different time periods, are being examined. Samples that were filtered at sea, stored in alcohol, and then dried by critical point drying in the laboratory have been found to yield the best results. Choanoflagellates, cryptomonads, and *Chrysochromulina* species are common, as are species belonging to several genera of the *Prasinophyceae*. A number of unknown organisms in the smallest size range (2 to 5µ) have been abundant at certain stations. Scanning electron microscopy is used routinely as an aid for identification of species. Transmission electron microscopy is also being employed for resolution of the surface scales, a diagnostic character in some groups. (Lewin, Booth; R.E. Norris, Department of Botany)

Modeling of Ecological Processes in the Subarctic Pacific Ocean

A numerical model of the trophic ecology of open waters of the subarctic Pacific, similar to that used by Steele and co-workers for the pelagic ecology of the North Sea, will include four trophic components: phytoplankton, herbivores, primary carnivores, and secondary carnivores. The model will be designed so that effects of physical conditions in different subregions of the subarctic Pacific may be investigated. Full realization of the model would provide an estimate of the carrying capacity of the subarctic Pacific Ocean for salmon. This estimate would be in the form of a quantitative statement of the law of diminishing return for increments in the scale of the international salmon ranching industry. Less than full realization of the model, nevertheless, will help to discriminate key ecological processes from minor ones before a major field research program, planned for the 1980's, is undertaken.

The model has been developed describing the annual cycle of phytoplankton and planktonic herbivores in open waters of the subarctic Pacific. The model depicts phytoplankton growth as a function of mixed layer depth, light, nutrients, and zooplankton grazing. A key feature of the model is control of phytoplankton growth in summer by zooplankton grazing; control is accomplished by simulating the population dynamics of the copepods *Calanus plumchrus* and *C. cristatus*. (Frost; C.B. Miller, Oregon State University)

Controlled Ecosystem Populations Experiment (CEPEX): Population Dynamics and Feeding of Larvaceans

Larvaceans are common in marine plankton, feed on very small particles, and may compete with copepods, especially their larvae, and other nanoplankton feeders. In the Controlled Experimental Enclosures (CEE) — large floating plastic cylinders in Saanich Inlet, B.C. — populations of *Dikoplea dioica* may double their numbers daily. In both the sea and the CEEs, drastic population declines are common, but were previously unexplained. Results from two summer experiments indicate that the abundance and structure of the larvacean populations are primarily controlled by the size and concentration of the available food and secondarily, by predation, particularly by the ctenophore *Bolinopsis*. Therefore, the major thrust of our current research in the laboratory is to

determine the effects of food size and concentration on the rates of growth, feeding, and fecundity in *D. dioica*. Preliminary results suggest that the animals require a substantial food supply to grow and reproduce and that they do not alter their feeding rates over a normal range of phytoplankton concentration. We have also shown, in cooperation with colleagues from Scripps Institution of Oceanography, that *D. dioica* is an extremely efficient bacteriovore and that the animal may receive a substantial portion of its daily ration from free-living bacteria. A simulation model investigating the impact of the larvaceans on the microbial populations in the enclosures is under construction. Laboratory experiments involving common invertebrate predators are planned for 1979/1980. (Banse [K. King])

Relative Abundance of Copepod Species in Temperate-Boreal Pelagic Communities

This project has the broad goal of identifying and analyzing the processes that affect the relative abundance of copepod species in marine epipelagic communities. The research currently stresses study of certain filter-feeding calanoid copepods of the genera *Calanus* and *Pseudocalanus* which are major components of the zooplankton in temperate-boreal oceans of the Northern Hemisphere. Laboratory studies on feeding behavior, growth rates, and reproductive rates permit quantitative description of intrinsic growth rates of copepod populations and the effects on population growth of several important environmental variables. To understand the role of predation in altering relative abundance of copepod species, laboratory experiments on feeding behavior of important planktonic carnivores are being carried out. Results are being integrated into simulation models of plankton to investigate theoretically the processes that control and modify interspecific interactions among filter-feeding copepods. Data are being obtained on the dynamics of natural populations of copepods occurring in Puget Sound.

Experiments on the selective feeding in adult females of *Calanus pacificus* have been completed and the results are available in recent publications and in a manuscript in press. Similar investigations are now being done with *Pseudocalanus* sp. Analyses of rates of growth and development of copepods under controlled laboratory conditions indicate that there are strong interactions between temperature, food abundance, and body size. That is, comprehensive understanding of patterns of growth can be achieved only with multifactor experiments. Laboratory studies of reproductive rates of *Calanus pacificus* at different food concentrations and temperatures generally agree with the results of laboratory studies of growth rate. Reproductive rates have been estimated for populations in Dabob Bay; results indicate that for much of the year the population is severely food-limited. A field study to test the hypothesis that grazing by zooplankton controls phytoplankton growth throughout the late spring and summer in open waters of the subarctic Pacific Ocean was completed recently. Briefly, the abundance of the major species of grazers (*Calanus plumchronus* and *C. cristatus*) was such that they could graze all the daily phytoplankton production if their ingestion rate was equivalent to 5% of their body weight per day. (Frost, Thoreson [Vidal, Runge, Yen])

Effects of UV-B Radiation on Near-Surface Zooplankton

Ultraviolet radiation in the middle wavelength range 280-315 nm (=UV-B) has important and practical biological effects. This radiation is of particular interest because it occurs in normal sunlight and would increase if the UV-absorbing stratospheric ozone layer were reduced. Precise information on UV

penetration into natural waters is not yet available, although the upper few meters of the sea surface receive appreciable UV radiation. This near-surface layer is environmentally important, and many zooplankters have their center of abundance there, or are found there at least for part of their life cycle. Many of these species are commercially important, and others have key roles in the ecosystem. If incident UV increases, it is this plankton group that would be most directly affected.

Shrimp larvae, crab larvae, and euphausiids were exposed to various low levels of simulated solar ultraviolet radiation (UV-B, 290-315 nm) under laboratory conditions. Comparisons between solar and artificial spectra were based on spectroradiometric measurements converted to erythemally effective irradiance. The experimental zooplankton tolerated UV-B irradiance levels up to threshold levels with no significant reduction in survival or development rates compared to control organisms. Beyond the threshold levels, activity, development, and survival rapidly declined. The apparent UV thresholds are near present incident UV levels.

Observed survival threshold levels for each experimental group were superimposed on seasonal solar incident UV levels at the experimental site (Manchester, Washington). These threshold levels appeared to be exceeded by median ambient UV levels late in the season of surface occurrence of each species. It is suggested that UV increases resulting from ozone depletion may significantly shorten this season. Although the apparent impact would be lessened by the decrease of UV with depth, irreversible detrimental sublethal effects would probably occur before reported survival thresholds are exceeded. (Damkaer; G.A. Heron, D.B. Dey, Pacific Marine Environmental Laboratory; E.F. Prentice, National Marine Fisheries Service)

Zooplankton Grazing on Oiled Particles

There have been numerous laboratory studies on the effects of hydrocarbons on marine organisms, but only a few of these dealt with zooplankton. (See also p. 23.) Besides investigating the effects of oil on zooplankton, some experiments have brought attention to the probable effects of zooplankton on oil. Copepods can ingest oil in suspension as well as oil adsorbed to particles (organic and inorganic). Some of this oil would be released via fecal pellets, a process that may have significant effects on the distribution and transformation of spilled oil in seawater. The dietary route of entry of hydrocarbons into zooplankton appears quantitatively much more important, and the hydrocarbons are far more persistent, than direct uptake.

The objectives of this new project are to evaluate the quantity and rate of oil uptake and transformation by zooplankton via oiled particles. (Damkaer; G.A. Heron, Pacific Marine Environmental Laboratory)

Flux of Organic Particulates to the Sea Floor

The fate of primary fixed carbon as it moves through the marine food chain is the objective of this project. Sediment traps are being used to investigate the passive movement of particulates out of the upper layers of the water column and their eventual deposition onto the sea floor. (See also p. 24.) Data of this type have been unavailable before. The traps, which are calibrated in situ with the use of lead-210, have been shown to collect $119 \pm 19\%$ of the material

that arrives on the sea floor. Data in hand indicate that carbon and nitrogen content, degradability, pigment content and composition, and other bulk chemical constituents are characteristic of the environment that produced them and have an impact not only on the organisms that may forage on them but may affect the portions of the water column through which they pass. Measurements of the flux of particulates, primarily fecal pellets, downwards out of the surface layers, through the mid-water regions and final deposition onto the sea floor, have been made in coastal and open ocean situations. Estimates of the flux of particulates have been obtained for an annual cycle in Dabob Bay, and for short-duration deployments on the Washington Shelf, and in two open ocean situations. (Lorenzen [Copping, Welschmeyer])

Identification of Marine Community Trophic Relationships in the Soft-Bottom Benthos

At the community level of organization, relatively little information is available on trophic relationships among soft-bottom, marine benthos. The general reliability of two methods, microscopic and serological examination of gut contents for identification of existing predator-prey relations among the macrofauna and meiofauna (larger and smaller invertebrates), are being compared. Serological methods are particularly attractive for the identification of prey items whose morphological identities cannot be determined. The intertidal community selected for experimentation allows both controlled laboratory evaluation via feeding experiments and field comparison of the two methods at regular intervals over a relatively long period of time.

Immunological methods have revealed many food web links that previously had not been established -- including apparent predation by supposed detritivores and predation by macrofauna on meiofauna. (Jumars, Feller [Taghon, Gallagher])

Ecophysiology of a Meiobenthic Copepod

Weight-specific respiration rates for several developmental stages of *Huntemannia jadensis*, a sand-dwelling harpacticoid copepod, were determined over the natural range of field temperatures. In addition, rates were determined for immature, egg-bearing, and spent females. Differences in respiration rates between stages, temperatures, and seasons will be described and quantified to allow extrapolation of laboratory results to previously investigated field populations of *H. jadensis*. In conjunction with the field production determined previously for intertidal sites in Puget Sound (R.F.), an energy budget for an entire year will be constructed. (Feller; F. Schiemer, Senior Fellow, Max Kade Foundation, New York, on leave from the University of Vienna)

Components of Bioturbation: Particle Selection by Deposit Feeders

Bioturbation is poorly understood because it embraces a heterogeneous mixture of processes, only a few of which have been isolated for detailed study. One of these components is particle selection for feeding and tube building. Research is being conducted to delineate the selective abilities of deposit feeders by using field tracer techniques. The development of a methodology that will permit direct assessment of the net effects of either particle ingestion or incorporation into tubes upon sediment transport, deposition, and mixing will be emphasized. These experiments concentrate on particle size and particle

specific gravity because they are explicit parameters in most sediment transport models.

The experiments show that deposit feeders select particles on the basis of specific gravity and surface texture. We are beginning to reveal the mechanisms whereby this selection takes place and to model its sedimentary impacts stochastically. (Jumars, Nowell, J.D. Smith, Self [Wells])

Life History of an Intertidal Amphipod

A study was made of the distribution, reproduction, growth, and mortality of *Dogielinotus loquax* in the vicinity of Ocean City-Ocean Shores, Washington. This amphipod inhabits a relatively narrow band in the upper intertidal on these high-energy sandy beaches. Quantitative core samples, using a stratified random sampling scheme, were taken at four-week intervals for 16 months.

D. loquax is an iteroparous species, with an average sex ratio of 1:1. Mean fecundity ranges from 8 to 32 eggs per brood, depending on the body length of the gravid female. The timing of peaks of reproductive activity (ratio of gravid to total females) and of recruitment events is strongly influenced by temperature-dependent rates of maturation and egg development. A generation recruited in spring reproduces in summer, resulting in a generation that grows slowly through the winter and reproduces the following spring.

From July through August the abundance of individuals recruited in spring declined rapidly (approximately 5% per day). Mortality, for the most part, occurred before maximal size was attained. Predation by shorebirds, particularly sanderling, may have been largely responsible. (Banse, Jumars [Hughes])

A Novel Method of Suspension Feeding by a Maldanid Polychaete

The membranaceous tube of *Prasillura maculata* Moore bears 6-12 stiff spokes of 2-3 cm length, arranged in nearly a single plane and approximately normal to the axis of the tube at the opening, 2-7 cm above the sediment. The tube is bent distally so that the plane of the spokes is strongly inclined toward the substrate. A mucus web with entangled food particles hangs between the spokes, but is not connected with the worm's body. The worm appears to obtain its food by swallowing the mucus. So far the method of feeding by a mucus web separated from the body is not known from the marine environment. It is the more remarkable because all other members of the Maldanidae, a moderately speciose family, are deposit feeders living head-down in the substrate. (Banse; N. McDaniel, Pacific Environment Institute, West Vancouver, B.C.)

Vertical Migration of Mesopelagic Fishes

Small mesopelagic fish are often associated with, and probably are the cause of, some deep sound-scattering layers in the open ocean. In order to comprehend for predictive purposes, the occurrence, intensity, and vertical distribution of deep sound-scattering layers at a particular oceanic locality, the vertical distribution, diel vertical migration, and feeding behavior of some small mesopelagic fishes (myctophid fishes or lanternfishes, family Myctophidae) are being investigated. Field sampling was carried out at two localities (Station P, 50°N 145°W; Station Q, 51°N 137°W) during three summers. Mesopelagic fish and zooplankton

were collected using obliquely-towed, electronically controlled, opening/closing nets of our own design. Aspects of the feeding behavior of three species of myctophids were adduced from analyses of their stomach contents.

In the upper 460 m, three species of myctophids (two migratory and one non-migratory) comprised 90% or more of the total mesopelagic fish. The two migratory myctophids fed most intensively in the near-surface layer at night but also fed at low rates in deeper water during the day. Types of prey utilized by the two species were very similar. In contrast, the nonmigratory myctophid fed almost exclusively during the day, and there was extremely little overlap of its diet with that of the two migratory species. The myctophids did not appear to adjust their vertical distributions to take advantage of aggregations of prey organisms, but the diel migrations of the two species did bring them into the near-surface layer where preferred species of zooplankton were often abundant. The field investigations revealed close correlations between distributions of sound-scattering layers (12 kHz echosounder) and distributions of myctophid fishes in the eastern subarctic Pacific. (Frost, Thoreson, [McCrone])

A General Investigation of Some Major Ecological Factors Determining Species Diversity and Abundance in Insular Systems

A project is underway to test some major hypotheses concerning island ecology and to modify the models generating these hypotheses in light of our results. The colonization process, the species-area and other faunal relationships, the distribution of individual species among islands, and the degree to which interactions between and within species control these patterns will be emphasized. Two very different island systems, an artificial-plate marine fouling system [A.S.] and a Bahamian small-island terrestrial system [T.W.S.], that are united only by their great tractability, will be investigated. The artificial-plate marine fouling system has a relatively low diversity, but individual species can be followed on the same plates through time without destruction of the community. By monitoring the history of plates of various sizes set out in Puget Sound, the number of species to area can be related through the intervening variable of population abundance. Thus a dynamic picture of the development of the species-area relationship will be obtained. We will also be able to see to what extent "average" species counts, abundance parameters, and so on result from very different species compositions generated via different historical pathways.

By creating an archipelago of fouling-panel islands in Puget Sound, Washington, the colonization of a series of artificial islands spanning three orders of magnitude in area can be followed. Observations of the colonization patterns of the panels for the one and one half years since the start of the experiment have produced the following results. Colonization curves for increasingly larger panels approach increasingly greater equilibrium species numbers. The species-area curves computed for these panels at successive times show a relatively rapid rise to a constant slope. Seasonal changes are reflected by slight alterations in this slope. Although both colonial and solitary species are present throughout the observation period, the former predominate initially, giving way to the latter; this is similar to patterns observed for temperate subtidal hard substrates and for most rocky intertidal substrates. The contribution of some early colonists to the resultant number of species later found on panels is examined, as well as the effect of individual species on the species-area curve. (A. Schoener; T.W. Schoener, Department of Zoology)

Colonization Patterns of Fouling Organisms

Hypotheses based on over a decade's NAVOCEANO panel experiments at several regions covering a wide range of latitudes in the Northern Hemisphere suggest some general trends in colonization by marine fouling organisms. In order to evaluate the generality of the results of these experiments, some additional questions must now be addressed. These concern a comparison of the nondestructive sampling technique of Sutherland (1974) and Sutherland and Karlson (1973, 1977) with the destructive sampling technique used by the NAVOCEANO labs, as well as an examination of panel-colonization variability in areas with a relatively large number of fouling species.

Preliminary results indicate variability in the species composition between panels; this is not unexpected based on Sutherland's and Karlson's results. Thus far, however, there seems to be a good deal of correspondence between the two types of sampling techniques in terms of mean number of sessile species found on panels. (A. Schoener [Greene])

CHEMICAL, BIO- AND GEOCHEMICAL OCEANOGRAPHY

Biochemical Investigations of Deep-Ocean Metabolism

The objectives of this project are to determine and explain the nutrient, salinity, temperature, and dissolved oxygen fields observed during biochemical investigations of deep-ocean metabolism. One aspect of the project, the estimation of the denitrification rates off South America, is nearing completion. The rate of denitrification between late 1976 and mid-1977 was $\sim 2 \times 10^{13}$ g N yr⁻¹ -- comparable to the rate estimated for the much larger oxygen deficient zone in the eastern tropical North Pacific. Our recent studies indicate that the 1976-1977 rate may have been higher than normal, and this view is confirmed by an examination of all available data on the nitrite maxima off Peru. The latter data suggest a recent increase in nitrite concentrations of the nearshore portion of the denitrification zone off South America, and we have found a positive correlation between nitrite concentration and denitrification rates. (Codispoti, Hafferty, Lowman, Wisegarver)

Nutrient Variability

During the major Coastal Upwelling Ecosystems Analysis (CUEA) field programs off northwest Africa and Peru, nutrient data were collected. Data analysis and synthesis is continuing. Several papers on the results of the research have been published or are in press, e.g., Codispoti, L.A. and G.E. Friederich (1978) Local and mesoscale influences on nutrient variability in the northwest African upwelling region near Cabo Corbeiro. *Deep-Sea Research* 25: 751-770; Codispoti, L.A., R.C. Dugdale, and H.J. Minas (In press) A comparison of the nutrient regimes off northwest Africa, Peru, and Baja California. Rapp. P.-v. Reun. Cons. perm. int. Explor. Mer.; Garfield, P.C., T.T. Packard, and L.A. Codispoti (In press) Particulate protein in the Peru upwelling system. *Deep-Sea Research*; Minas, H.J., L.A. Codispoti, and R.C. Dugdale (In press) Nutrients and primary production in the N.W. African upwelling region. Rapp. P.-v. Reun. Cons. perm. int. Explor. Mer. (Codispoti, Hafferty, Lowman, Wisegarver)

Participation in an experiment in the upwelling region off Somalia includes collecting a complete suite of nutrient data. These data, combined with the physical and meteorological data that will be collected, should provide significant new information on the nutrient variability and some of its causes during the transition period from no upwelling to strong upwelling that occurs during the Southwest Monsoon. Further, coupling of the nutrient data with information on nutrient uptake and regeneration rates also will aid in understanding the causes of the observed nutrient variability and will permit comparison with similar suites of data from northwest Africa and Peru.

In addition to providing information on the Somali Current and its associated upwelling, the design of the experiment is intended to describe mesoscale eddies that commonly are found offshore of the Somali Current. At present nothing is known about the effect that these eddies may have on the nutrient regime off Somalia. It also is hoped that new information on the days to weeks nutrient variability will be forthcoming by correlating these discrete nutrient data with the continuous wind, current, and temperature data that will be available. (Codispoti, Friederich, Wisegarver)

Anaerobic Nitrite in the Tropical Northeastern Pacific

An experimental program (METREX) was designed to investigate the processes controlling the oxygen minimum and anaerobic nitrite features of the tropical northeastern Pacific. A model of the distribution of nitrite has been developed that is based on biochemical reactions and physical diffusion. Additionally, methods have been developed to measure the continuous distributions and the reaction rates of nitrite. To test and improve the model, a field experiment was carried out in which the vertical profiles of the chemical constituents and biochemical reactions were obtained at a site in the tropical northeastern Pacific.

A new method was developed for obtaining estimates of in situ rates of oxygen consumption and nitrate respiration. The bacterioplankton from large volumes of seawater (100-2000 liters) are retained in cartridge filters and a much smaller volume of seawater is recycled through the cartridges and changes in oxygen tension and nutrient concentrations are monitored by oxygen electrode and Autoanalyzer, respectively. In situ oxygen consumption rates as low as $8 \text{ ng-at } 0 \text{ l}^{-1}\text{h}^{-1}$ have been estimated and independently verified for samples from the aphotic zone of a local fjord.

The denitrifying spaces in the eastern tropical North Pacific are being compared to those of the coastal waters of Peru and the Arabian Sea. (J.J. Anderson, R.J. Ozretich)

Sources and Sinks of Marine Nitrous Oxide

The production mechanisms and fate of nitrous oxide in the marine environment are being investigated. Recent measurements in the ETNP confirmed that N_2O is consumed during denitrification; however, it is produced in excessive amounts in zones where the oxygen concentration is low, but not zero. The major production process appears to be nitrification. Thus, the oceans appear to be a large source for N_2O , but very little of it escapes to the atmosphere. (Cline, J.J. Anderson)

Metabolic Studies in Anaerobic Sulfide Bearing Waters

When dissolved oxygen is depleted, certain anaerobic bacteria that are capable of using sulfate as the terminal electron acceptor in their electron transport system (ETS) can become active. This process -- sulfate reduction -- results in the formation of the highly toxic reduced gas, hydrogen sulfide. Sulfate reduction is generally confined to the sediments, but in basins with a high influx of organic matter coupled with restricted bottom circulation, hydrogen sulfide can sometimes accumulate in the water column. Two such basins currently under investigation are the fjords, Lake Nitinat and Saanich Inlet, Vancouver Island, British Columbia. (See also p. 9.)

ETS activities in the water column and sediments of both Lake Nitinat and Saanich Inlet have been measured. Activities are much higher in the sediments than in the water column which is probably related to the higher organic content of the sediments and hence to the greater numbers of microorganisms that can be supported. Sulfate reduction in the sediments has also been measured using ^{35}S -sulfate and by other more indirect techniques. Although highest activities are generally confined to the surface sediments, a subsurface maximum has also been

observed. It is not yet clear whether this subsurface maximum, if real, is related to a similar maximum in sulfide concentration. ETS activities suggest that this may be the case.

An enzymatic assay for the measurement of sulfate reducing activity is being perfected and compared with ETS activity and sulfate reduction by the ^{35}S -sulfate technique.

Heterotrophic oxidation and utilization of selected organic compounds have been measured in the water column of both Lake Nitinat and Saanich Inlet. The compounds tested to date have been lactate, acetate, and a mixture of amino acids. General trends are higher activities in the surface waters and at the interface between the oxygenated and sulfide bearing waters, and lower activities at intermediate depths. There is usually an increase in heterotrophic activity close to the bottom. Acetate is generally oxidized more rapidly than lactate, even in the anaerobic zone. This observation is especially intriguing because the only known mechanism for the anaerobic oxidation of acetate in marine environments is by the methanogenic bacteria which are believed to be inactive in the presence of hydrogen sulfide. Amino acids appear to be preferentially incorporated rather than oxidized, and the ratio of incorporation to oxidation may be a useful physiological indicator. (Ahmed [S. King])

Nutrient Diagenesis in Marine Sediments

The chemical composition of interstitial solutions is a sensitive indicator of the reactions of organic matter in the sediments. In the sediments of the fjords around Puget Sound these reactions are rapid and sulfate reduction commences soon after burial. Between Puget Sound and Cascadia Basin there is a transition zone in the sediments that separates the sulfate reducing sediments from the bottom water. In this transition zone reactions involving nitrogen species occur. The hemipelagic sediments are of special interest because the nitrogen reactions in these locations may have great bearing on the global nitrogen cycle.

Complete sets of pore water and sediment data that can be used to model the diagenesis of organic matter in marine sediments are being collected. Analyses include nutrients (NH_4^+ , NO_3^- , NO_2^- , Si, PO_4^{3-}), major ions (Cl, Ca, Mg, SO_4), pH, alkalinity, trace metals (Cu, Ni), DOC, $\delta^{13}\text{C}$ and gases (O_2 , AR, N_2 , CO_2 , CH_4). As part of this project, a new in situ interstitial water sampler suitable for collecting gas samples has been developed.

To date, Puget Sound, Saanich Inlet, Cascadia Basin, Guatemala Basin, and the Central Equatorial Pacific data have been collected. A major cruise is planned for October 1979 to sample hemipelagic sediments off Mexico. (Murray [Grundmanis, Kuivila, Sawlan])

Hydrocarbons in Puget Sound

A program of studies of aliphatic and aromatic hydrocarbons in organisms, sediments, and waters of Puget Sound and the Washington shelf north of the Columbia River was begun in summer 1975 (see p. 23). Overall goals in this research are to increase our understanding of:

- 1) the distribution of aliphatic, aromatic, and sulfur- and nitrogen-containing molecules in the organisms, sediments,

and water column at the present time while the distribution is still primarily due to natural processes;

- 2) the composition of the hydrocarbons derived from river input, sewage discharges, and atmospheric rainout and their importance compared to biosynthesis by marine organisms;
- 3) the patterns of transfer of certain of these hydrocarbons between some well-defined parts of the marine food web.

These clearly large and complicated problems are being attacked with a variety of techniques: gas chromatography, ultraviolet fluorescence spectroscopy, high pressure liquid chromatography, mass spectroscopy, and radiocarbon and C^{13}/C^{12} determinations. J. Hedges is supervising the gas chromatography studies; R. Carpenter, the liquid chromatography and UV fluorescence studies; A.W. Fairhall, the radiocarbon and C^{13}/C^{12} studies.

Eight seasonal samplings of phytoplankton, zooplankton, and neuston have been carried out at about 40 stations in Puget Sound. Stations were chosen to provide geographical coverage of Puget Sound; they include many stations previously sampled by B.W. Frost to determine the seasonal distribution of plankton. Also included is a set of closely spaced stations, near the sites of major refineries, in the area north of Bellingham. (Carpenter, Hedges, and students; A.W. Fairhall, Department of Chemistry)

Chemical and Geochemical Studies off the Washington Coast

Four main lines of investigation are being carried out on the continental shelf off the Columbia River:

- 1) surface chemistry of the scavenging of various species dissolved in seawater, especially As, by well characterized natural particulates (based on the hypothesis that the removal of many radioactive and non-radioactive elements from seawater is dominated by surface chemical reactions between dissolved species and particulate phases);
- 2) uptake and transfer of several isotopes, starting with Po^{210} , by particularly well defined parts of the marine food web that we are in a unique position to study. (Po^{210} forms the major dose of internal radiation to a number of marine organisms, so its cycling through the environment and marine food web is important both in terms of its possible effect on marine organisms and on human consumers of marine organisms.)
- 3) Pb^{210} and Po^{210} in sediments, with the dual aims of learning more about these two natural radioisotopes in the sea and determining accumulation rates of Columbia River derived solids on the continental shelf and slope over the past 100 years;
- 4) aliphatic and aromatic hydrocarbons in samples of phytoplankton, zooplankton, and neuston, and in sediment cores using the same sampling gear and analytical procedures as in the Puget Sound hydrocarbon studies (see p. 21). (Carpenter and students)

Sorption-desorption studies of trace metals: Over the past few years, we have acquired or developed the ability to determine for suspended matter samples the following properties: mineralogy by X-ray diffraction, organic carbon and nitrogen contents, major and minor element chemistry by nondestructive neutron activation and thin film energy dispersive X-ray fluorescence, and surface area by the BET technique of nitrogen gas adsorption. The combination of these analytical capabilities makes it possible to work with concentrations of dissolved chemical species and suspended matter much closer to natural concentrations than previously and therefore to better characterize the suspended matter.

Surface chemical scavenging reactions between the wide variety of radioactive and stable elements and the particulate phases naturally present in coastal and estuarine areas are being investigated. Sorption-desorption studies with mercury have been completed (Bothner and Carpenter, 1973). A series of sorption-desorption studies with arsenic and preliminary studies of the scavenging of dissolved lead by natural marine particulates using the 10.5 hour tracer Pb^{212} have been carried out. Samples of the organic rich suspended particulates collected from Saanich Inlet in August sorbed only about 15% of the radioactive As^{74} arsenate, with 15-25% of the tracer being sorbed within two to three weeks.

Additional studies of the sorption of the radioarsenate showed that the ferric hydroxides have great affinity for dissolved arsenic; over 90% of the arsenate was taken up within 20 hours by the ferric hydroxides and, at most, 1-2% of this could be desorbed by placing the spiked solids in unspiked seawater with one half or one fifth the arsenic concentrations. The manganese oxides were comparable to the Puget Sound particulates and much less effective at scavenging the dissolved arsenic than the ferric hydroxides. Two marine ferromanganese nodules were also extremely effective scavengers of dissolved arsenate, and the arsenic they sorbed was not released in the desorption experiments. This behavior presumably is due to their iron, rather than their manganese, compounds. The results of these experiments show rather clearly that hydrous iron oxides are much more effective than inorganic clays, manganese oxides, or organic rich suspended matter as scavengers of dissolved arsenic. (Carpenter [Jahnke]).

Sediment studies with lead-210 and ^{14}C techniques: The chemistry and mineralogy of the suspended particulates, the clay mineralogy of bottom sediments, as well as the accumulation histories over the past 100 years and over the past 7000 years, of the continental shelf, slope, and the canyons indenting the slope are being determined. For these determinations and the hydrocarbon studies described below, our special corer with hydrostatically damped rate of penetration into the sediment to sample the sediment-water interface with the least possible disturbance was used. This corer takes four cores, each 1-2 feet long, and thus gives replicate samples going back in time. The lead-210 derived accumulation patterns support the idea that more sedimentary material is transported down these canyons to the deep sea than is transported over the shelf break and down the open continental slope (see also p. 29.) (Carpenter [Bennett])

Hydrocarbon studies: Samples of phytoplankton, zooplankton, neuston, and sediments have been collected on four transects across the shelf off Washington (1975-1977). (See also p. 21.) Given the limited amount of data on hydrocarbons in all types of samples from both Puget Sound and the Washington shelf,

it is most important to determine the quantities and types of hydrocarbons present in organisms first, sediments second, and finally in the water. This is partly because it is the impact on the organisms which is of greatest concern, and partly because the analysis of hydrocarbons dissolved in seawater is still a very difficult task. Accordingly, we are concentrating our sampling and analytical programs on organisms and sediments. (Carpenter, Hedges [Bennett, Prahl, Clark, Rosa])

Use of Chemical Tracers to Measure Vertical Mixing Rates

Vertical mixing rates in the top of the open ocean pycnocline using naturally occurring radon-222 and radium-226 are being investigated. Aspects of the project include (1) the development of high precision radon counting cells, (2) determining the feasibility of collecting closely spaced large volume (2m) samples, using 30 liter Niskin bottles and a submersible pumping system, and (3) field testing all radon equipment and sampling methodology by conducting an intensive survey of radon in a local fjord, Dabob Bay. In the following year or so, a major field operation will be mounted at a selected ocean site on a ship of opportunity where other complementary studies will be undertaken simultaneously.

Significant improvements in the counting system have been made this year, and all PVC counting cells have been recalibrated. Based on a total of 34 determinations on 27 counting cells, the precision of the counting cells is $1.7 \pm 0.9\%$.

In the near-surface water, the oxygen gradients measured with 30-l bottles oscillating 2 m and 4 m were in good agreement with the oxygen gradient measured using small bottles with good flushing characteristics. The oxygen gradient obtained with a submersible pump oscillating 2 m was also in good agreement with the gradient obtained using small bottles. Thus both methods appear to be feasible for collecting 30-l radon samples in the top of the pycnocline.

During the summer of 1978, bottom water radon profiles were measured on five consecutive slack waters at a station located in the center of Dabob Bay and radon concentrations were measured in the bottom 40 m on a longitudinal and a transverse section. CTD casts were made with each radon cast, but these data have not yet been analyzed. There was some tidal variability in the vertical distribution of radon. The radon concentration measured on the longitudinal and transverse sections showed that the radon concentration isopleths were approximately parallel to the bottom topography indicating that horizontal mixing is not rapid relative to the decay rate of radon. A homogeneous layer of radon was observed in the bottom few meters in the central region of the fjord but not in the rest of the fjord. (Schell [Smethie]; R. Lusk, Fisheries Research Institute)

Association of Humic Materials with Copper in the Sea

The stability of copper bound by humic substances in the open sea is being investigated by the following procedure: The humic substances in the water column are collected on adsorption resins with a pumping system; humic substances in the suspended phase are collected by sediment traps. (See also p. 14.) Extracts in the form of concentrated humic and fulvic acids are added to seawater. Each sample is subjected to complexometric titrations with copper

and is analyzed by anodic stripping voltammetry. The results yield conditional stability constants when strong complexing occurs. The relationship between metal binding stability and the nature of the particulate matter will be investigated.

The study of the stability of the copper association with seawater humic substances has been completed. Currently, material from eastern Pacific sediment trap samples is being processed. (Healy, Lorenzen [Lieberman])

Geochemistries of Trace Metals

Arsenic in Puget Sound: A budget of arsenic fluxes in Puget Sound has been developed with the aim of determining the rate of movement of arsenic through the four Puget Sound subbasins and the ultimate fate of both natural and anthropogenic arsenic introduced to Puget Sound. This information is needed to be able to predict the concentrations of arsenic with time in different parts of Puget Sound, given various natural and anthropogenic inputs at different places around the sound.

The natural distribution of arsenic is modified by a copper smelter that releases large amounts of arsenic in stack dust to the atmosphere and in liquid effluent directly into Puget Sound. The airborne material contributes arsenic to lakes and soils up to 50 km downwind and supplies about the same amount of arsenic to Puget Sound as do rivers and the liquid effluent of the smelter. The major source of arsenic is clearly the inflowing seawater. Most of the dissolved arsenic entering Puget Sound is removed by advection of surface waters to the Strait of Juan de Fuca. Sedimentation processes, including adsorption-desorption reactions with natural Puget Sound suspended matter, remove less than 15% of the dissolved arsenic input. Hydrous iron oxides appear to dominate the amount of dissolved arsenic that is removed. Both bell jar studies and analyses of arsenic in cores collected at the same station five years apart show there is no large flux of dissolved arsenic from the sediments back to the overlying seawater. Vigorous tidal action quickly dilutes the anthropogenic arsenic; hence, concentrations of arsenic in waters and organisms of most of the sound are not elevated above natural concentrations.

In addition to determining total arsenic concentrations in waters of the Puget Sound region, studies of the chemical form in which it is present have been carried out, using techniques developed by Braman and coworkers at the University of South Florida. Most of the arsenic in the normal oxidizing seawater of Puget Sound is clearly arsenate, the thermodynamically stable form. The discharges from the Tacoma smelter are largely arsenite, however, and arsenite is much more toxic to most marine organisms than arsenate. (Carpenter, M.L. Peterson)

Mercury in Bellingham Bay: The amounts of mercury in sediments in Bellingham Bay, to the north of Puget Sound, have been investigated as a function of time since the mercury discharge to the bay from a chlor-alkali plant was stopped in 1970. This is the only field study to our knowledge that is determining the rate at which an estuarine system responds to the cessation of mercury pollution. Our first study on the geochemistry of mercury showed that the sediments were not a permanent sink for the mercury that was discharged by the chlor-alkali plant and initially deposited in nearby bottom sediments.

After the industrial input essentially was eliminated, the time required for mercury concentrations in these sediments to decrease by a factor of two was about 1.3 years -- a surprisingly short time. Subsequently, we have been successful in modeling the changes in mercury in the sediments with time by combining the sediment mixing model of Guinasso and Schink with ^{210}Pb derived sedimentation rates, depth of surface sediment mixed layer, and mixing coefficient. Mercury concentrations, that had decreased steadily since 1970 at one station in Bellingham Bay, jumped suddenly in 1974, apparently because some severe storms and deliberate dredging operations resuspended some of the mercury rich sediment in the immediate area of this discharge, causing it to be transported out to some parts of the bay.

The first direct field measurements of the rates at which mercury moves from contaminated oxidizing and reducing sediments to the overlying seawater were those made in Bellingham Bay with an aerated jar apparatus. In the reducing sediments a flux of 2×10^{-5} ng total Hg/cm²/sec, presumably in response to a strong concentration gradient of dissolved mercury between interstitial and overlying seawaters, was readily measurable. The form of the mercury released was nonvolatile, so it was not species like elemental mercury or organomercury compounds such as the expected methyl or dimethyl mercury. No flux of dissolved or volatile mercury across the sediment-water interface was measurable for the oxidizing sediments, possibly because both interstitial and overlying seawaters had similar mercury concentrations.

The bell jar apparatus has also proven useful in determining fluxes of nutrients and arsenic and other chemical species across the sediment-water interface from both oxidizing and reducing sediments of Puget Sound. (Carpenter, Bothner, M.L. Peterson, Emerson)

The Fate of Trace Metals in the Marine Environment

Research on the surface chemistry of metal oxides and the fate of trace metals in estuaries is continuing: (1) Surface chemistry experiments have been designed to bridge the gap between the laboratory and the natural aquatic environment. A well characterized surface [goethite] is used in these experiments and the effect of the natural salt concentrations and organic matter on the basic surface properties and adsorption of PO_4 , Co(II) and Ni(II) is being evaluated. (2) The unusual properties of MnO_x are being investigated and the effect of divalent cations on the mineralogy of manganese oxides is being evaluated; (3) The form and chemistry of Fe, Mn, Cu, Ni, and Zn in the Skagit River Estuary is being determined.

Laboratory studies of the surface chemistry and trace metal binding with goethite (α FeOOH) and birnessite (MnO_x) are being conducted to obtain a consistent set of data that can be used to model adsorption in the marine environment. We also have used XPS to determine the oxidation state of some of the adsorbed metals (Co and Pb).

In field studies, the distribution of Fe, Mn, Cu, Ni, Cd, Cr(III) , and Cr(VI) in seawater and pore water is being determined. The chromium profiles appear to be the best yet measured. Our studies indicate that the continental slope is a source for Mn and Cr(VI) and that these metals then are dispersed into the interior of the ocean principally by horizontal mixing. The pore water

Cu and Ni profiles reveal that these metals are released when MnO_2 is reduced. These features will be studied in greater detail during a cruise from Honolulu to Mazatlan in October 1979.

A detailed study of hemipelagic sediments and nodules collected from the Guatemala Basin also will be undertaken. These nodules are important because they come from a location where there is a strong flux of Mn from the underlying sediments. (Murray, Paul [Jones, Sawlan, Cranston])

Manganese Nodule Program

The objective of MANOP is a detailed study of the influx, remobilization, and final deposition of transition metals supplied to the deep-sea floor of the central eastern Pacific. Remote observations and experiments at the sea floor were conducted using bottom ocean monitors (BOMs), which were emplaced for periods of several months. Two BOMs were deployed in each of the major sediment facies of the region -- siliceous ooze/clay, calcareous ooze, hemipelagic clay, metalliferous (rise crest) sediment; and pelagic brown ("red") clay. During the 1977-78 biennium, efforts were concentrated on (a) the design, fabrication, and testing of the first BOMs; (b) deep-tow surveys of two proposed BOM sites; (c) intercalibration and development of sampling procedures for the analytical programs; and (d) deployment of the first BOM in a siliceous clay area at 11°N , 140°W . MANOP also conducted complementary projects on the precipitation of manganese by marine bacteria, and on the relation of nodule size distributions to models of accretion and burial.

Diagenesis and diffusion in interstitial waters: The analysis of the pore waters at the hemipelagic and metalliferous (rise crest) locations shows that oxygen is consumed entirely in the top 2 cm of sediment. The nitrate results indicate that the rise crest sediments are more reducing than the hemipelagic (Guatemala Basin) sediments. Manganese is remobilized in the pore waters within 20 centimeters of the sediment-water interface in both locations. (Emerson [Jahnke])

An in situ adsorption experiment: An in situ adsorption experiment on the seabed and in the water column is being conducted. Carefully characterized iron and manganese phases will be exposed to natural seawater, and the changes in properties and chemical composition that take place with time will be examined. This will be the first attempt to directly test the hypothesis that adsorption of trace metals on hydrous metal oxides is the mechanism by which these metals are enriched in ferromanganese nodules. This is also the first attempt to extrapolate laboratory adsorption isotherms to the deep sea.

Measurements of cobalt adsorption as a function of concentration at pH 8.0 on a wide range of solid phases have been completed. A pump built for the in situ experiments is being tested. (Murray, Balistreri)

Lignin Geochemistry of Quaternary Sediment Cores

Lignin compounds are being used as indicators of terrestrial plant remains in cores of Quaternary sediment. These organic polymers are useful tracers of land-derived organic matter in sedimentary deposits because they are not only unique to terrestrial plants but their chemical structures indicate the type of land plant from which they come. Sedimented lignins are determined by

oxidation with cupric oxide to form simple phenols that are analyzed by gas-liquid chromatography. Sediment cores representative of Lake Washington and the Washington continental shelf are being analyzed. These cores contain sediments up to 10,000 years old. The goals of the research are: (1) to search for new applications of lignin compounds as indicators of terrestrial plant remains; (2) to determine the lignin geochemistry of modern sediments from the Washington continental shelf; and (3) to determine the chemical stability of lignin compounds in lacustrine and marine sediments.

Results to date indicate that:

- 1) The cinnamyl phenols p-coumaric acid and ferulic acid are produced from the oxidation of nonwoody vascular plant tissues but, not to an appreciable extent, of woods. It, therefore, is possible to discriminate between woody and nonwoody tissues on the basis of cinnamyl phenol yield in addition to the classical characterization of gymnosperm and angiosperm tissues according to syringyl phenol yield.
- 2) The land-derived organic material in sediments from the Washington continental shelf is most concentrated near the mouth of the Columbia River and in the midshelf silt deposit to the north. Lignin composition over this region is relatively uniform with gymnosperm woods being the predominant component of the sedimented mixture of vascular plant remains.
- 3) The lignin compounds in these coastal sediments are chemically stable for time periods of up to 400 years and, therefore, should be useful geochemical indicators in older sedimentary deposits. (Hedges)

GEOLOGICAL AND GEOPHYSICAL OCEANOGRAPHY

Shelf Sediment Dynamics Program

This plan for a long-range study of continental shelf sediment dynamics is in the preliminary phase. The scientific goals of the proposed program include the theoretical and quantitative investigation of modern sedimentary processes; and quantification of depositional facies development with applications for interpreting the sedimentary records and the Recent geological history of continental shelves. The goals of the program not only possess intrinsic scientific value but also have vital applications for the practical matters of resource and environmental management.

A quantitative approach in the form of an integrated model is proposed. The model framework consists of five scientific components: (1) shelf sedimentology and stratigraphy, (2) physical oceanography, (3) sediment transport mechanics, (4) sediment/organism interactions, (5) near-bottom flow and sediment transport. The outputs of the sedimentation model are multifold. Each component is an important research effort in its own right and will produce independent scientific results pertaining to shelf sedimentary processes. In addition, the interaction of components will broaden the scope of the study -- providing results applicable to the geological record.

During the preliminary phase, the Executive Committee has received letter proposals from interested scientists who wish to participate in the program. The letter proposals have been reviewed and will form the nucleus of a multi-institutional scientific proposal to be submitted to IDOE/NSF for funding to commence in June 1980. (Sternberg, J.D. Smith, Jumars)

Sediment Transport in the Nearshore Environment

An in situ field program to determine the nature and relative importance of suspended sediment in the overall long-shore transport process is underway. In the initial phase, the Sediment Dynamics Group (UW) successively evaluated sediment sensing and sampling instrumentation and methodology. A prototype integrated system comprised of various electronic sensors and mechanical samplers for obtaining time-series suspended sediment data in the surf zone was constructed. Field testing and calibration will be accomplished both locally and in conjunction with ongoing field programs at Scripps Institution of Oceanography and the Naval Postgraduate School. Our instrumentation system will be compatible electronically and mechanically with the mounting frames and data acquisition/transmission system utilized by other participants.

The first field study using this experiment was carried out in conjunction with scientists from several other institutions at Torrey Pines Beach in November 1978. Continuous observations were made of suspended sediment concentrations within the surf zone over a range of wave conditions. The data are being analyzed to determine the relationship of sediment suspensions to flow conditions; the spatial distribution of suspended sediment within the surf zone; and total and net longshore transport of sediment. (Sternberg, Lister, Morrison [Downing])

Modern Sediment Accumulation on the Washington Continental Shelf

During the past two years a relatively new radioactive technique for dating marine sediments back 100-150 YBP has been applied to the continental

shelf of Washington. The objectives are to measure the accumulation rates for surficial sediments and to estimate a sediment budget for the Washington continental shelf. Seasonal variations of sediment accumulation are also being investigated as well as processes of sediment mixing resulting from benthic infauna and from storms producing severe wave action and bottom currents on the continental shelf. (See also p. 23.)

The results of this investigation to date are as follows:

A sedimentary deposit characterized by high accumulation rates emanates from the Columbia River and extends north-northwestward across the mid-shelf region toward the Quinault submarine canyon. This deposit consists mainly of silt and some very fine sand, both supplied by the Columbia River, and is bounded shoreward by a deposit of modern sands and seaward by a palimpsest deposit composed of relict sand and modern silt and clay. A preliminary sediment budget indicates that 1.4×10^7 metric tons of silt and clay and 1.0×10^7 metric tons of sand accumulate each year on the mid and outer continental shelf.

Pb-210 profiles indicate a surface mixed layer (about 10 to 20 cm thick) where physical and biological processes actively affect the resuspension, transport, and accumulation of sediments. These short-term processes averaged over long time scales ultimately control the observed sediment budget. To evaluate the effects of physical and biological processes on shelf sedimentation, we have developed a multi-systems approach that involves the simultaneous investigation of: (1) wave and current activity, and sediment movement (with an instrumented tripod); (2) benthic biology; (3) sedimentary structures; and (4) depths of erosion and biological mixing (through both Pb-210 geochronology and Rn-222 disequilibrium studies). (Sternberg, Nittrouer)

Field Study of Sediment Dynamics Under Ocean Waves

Field experiments are being conducted on the Washington continental shelf to evaluate the relationship between the threshold conditions for sediment resuspension and surface wave motions. Mathematical equations to predict threshold conditions for resuspension have been verified in the laboratory; however, at present the results of only one field study are available. This study will bring into perspective field observations taken under a variety of oceanic conditions and should increase our ability to predict sediment motion under ocean waves.

A microprocessor controlled tripod was constructed and has been deployed in many locations. In the most recent deployment, December 1978, a 15-day record of sediment erosion was obtained on the Washington Continental Shelf during a period of time when waves dominated the erosion process. The depth of deployment was 91 m. (L.H. Larsen, Sternberg, Lahore, G. Peterson, Rourke)

Suspended Sediments in the Arctic Ocean

The Sediment Dynamics Sphere (SDS) was deployed to measure near bottom velocities, wave conditions, and sediment concentrations in the Arctic Ocean.

A mooring was set out in Simpson Lagoon in August 1978. The 12-hour record is being analyzed. An attempt to obtain a longer record will be undertaken in the summer of 1979. (L.H. Larsen, G. Peterson)

Acoustic Remote Sensing

The development of a research program and associated instrumentation for using acoustic backscatter systems for the remote monitoring of suspended particle distributions, internal wavefields, frontal zones, and gradients of other properties in natural waters is being undertaken. The first year's efforts will be devoted principally to preliminary field tests of various acoustic systems. (E.T. Baker)

Coastal Zone Color Scanner Validation Studies

This project is concerned with the development of algorithms for the Coastal Zone Color Scanner (CZCS) satellite system and participation in at-sea validation of the CZCS information after launch. The prelaunch experiment, a cooperative venture, including investigators from NOAA, NASA, Scripps, Texas A&M, and Bigelow Laboratory for Ocean Sciences, was carried out in 1977 in the Gulf of Mexico. This experiment was designed to ascertain the usefulness of measuring phytoplankton pigments and suspended sediments with remotely sensed water color measurements. A paper on the "Upwelled spectral radiance distribution and its relation to various fractions of the particulate matter in marine waters" is in press. (E.T. Baker; A. Strong, NOAA National Environmental Satellite Service, Washington, D.C.)

Rock Magnetic Studies of Sedimentary Cores from the Pacific Ocean

Magnetic studies to better define the chemical environment and the effects chemical changes have on magnetic minerals in marine sediments are continuing. Various Fe-Mu-oxide minerals and their magnetic properties are being examined. Numerous geochemical tools (including neutron activation, atomic absorption, and SEM) are being combined with magnetic studies (including ARM and FMR) in the analysis of actual and "synthetic" marine sediments. (Merrill, H.P. Johnson [G. Smith, Department of Geophysics])

The interaction between paleomagnetic data and theories for the origin of the earth's magnetic field is being investigated. This involves analyses of the directional and intensity data for the earth's magnetic field to determine the constraints placed on theoretical models. (Merrill; M.W. McElhinny, Australian National University)

Theoretical rock magnetic studies are underway. To better understand the origins of magnetic properties in rocks, etc., various theories are being developed, e.g. how to determine the demagnetization field in multi-domain grains and the origin of rotational remanent magnetization. (Merrill [G. Smith, Department of Geophysics])

Long-Term Anomalies in the Time-Averaged Paleomagnetic Field and Oceanographic Secular Variation

Cooperative work with the Australian National University on long-term anomalies in the time-averaged paleomagnetic field and on geomagnetic secular variation is being continued. The time-averaged reverse polarity field has been found to be significantly different at the 95% confidence level from the normal polarity magnetic field. This disparity could have serious consequences on almost all dynamic theories for the earth's magnetic field. Investigations

designed to find out if such differences are reflected in the geomagnetic secular variation records have been started. (Merrill; M.W. McElhinny, The Australian National University)

Deep Crustal Drilling in Southeastern Iceland

Because the present state of knowledge of oceanic crust has suffered from the lack of successful sampling of more than 600 meters of an in situ oceanic igneous crust, a project was undertaken to drill a deep (roughly 2 kilometers) continuously cored hole in the igneous crust of southeastern Iceland. This project was a joint effort of the United States, Canada, West Germany, England, and Iceland. (See also p. 36.)

The drilling program during the summer of 1978 produced a 1920 meter drill hole that had a 99.7% recovery of the core. Detailed geochemical, petrological, magnetic, and physical property studies of the core material are in progress. Preliminary magnetic results show a continuously decreasing magnetic susceptibility and intensity of remanence with increasing depth (and increasing degree of burial metamorphism) in the drill hole. This may imply that metamorphic effects control the bottom of the magnetic anomaly source layer in oceanic crust rather than Curie temperature isotherms. (H.P. Johnson, Delaney, Lewis, Merrill [J. McClain]; S.W. Smith [Thomson], Department of Geophysics)

A Marine Geophysical Study of an IPOD Drill Hole Site

The purpose of this project was to study in considerable detail the ocean crust at the mouth of the Gulf of California prior to drilling under the International Program of Ocean Drilling (IPOD). The study used marine seismic refraction and reflection methods in addition to heat flow, magnetics, and bottom sampling. The outcome of the geophysical work was a three-dimensional picture of the crustal velocities in the area, sediment distribution and thickness, upper mantle velocities and anisotropy, and heat flow variability. Drilling in this area confirmed the sediment thicknesses, heat flow, and seismic velocities obtained in the survey. Work is continuing on the interpretation of the seismic velocities in terms of petrology and on the magnetic anomalies in terms of the source of the anomalies. (Lewis, Lister)

A Study of the Pacific Northwest Subduction Zone

An onshore-offshore experiment to study subduction in the Pacific Northwest has been carried out. The major goals of this experiment were a description of the oceanic lithosphere and what happens to it under the continent. We tested the hypothesis that a low velocity low strength zone postulated at the base of the oceanic crust and at the base of the continental crust under Puget Sound are related and show the oceanic plate sliding under the continent. An alternate hypothesis that the oceanic lithosphere dips at about 50° under the continent was also tested. To do this an array of ocean bottom seismometers was deployed at the base of the continental slope to monitor seismic activity under the margin and refraction shooting on the oceanic plate. Simultaneously, a land array monitored the same events. Later a fixed ocean shot point and moving land stations will be used to run a 500 km refraction line across the Cascade Mountains to investigate the deep structure under Puget Sound and the volcanic mountain belt.

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To date, the field work has been accomplished. Analysis of the data will form the thesis material for two graduate students. (Lewis; S.W. Smith [K. McClain, Taber], Department of Geophysics)

Analysis of Seismic Refraction Data from a Continental Margin

Data from a marine geophysical site survey done for the International Phase of Ocean Drilling (IPOD) are being analyzed. The site near the margin of Baja California was selected for drilling by IPOD, and detailed study of the survey data beyond the work already done was warranted.

Four aspects of the sea floor will be studied. They are: wave propagation (seismic waves) in ocean sediments using explosions set off on the bottom and ocean bottom seismometers; the P wave velocity structure at the drill site for later comparison with drilling results; the way in which the continental crust, west of the site, borders the oceanic crust to the east, using surface explosions - we hope to be able to determine if the change is abrupt, or if there is some transitional crust between the two; and the shear wave velocity structure. Because of the site where data were taken and our instruments, unusually clear shear wave arrivals are available. (Lewis, [Tuthill, Department of Geophysics])

A Seismic Refraction Investigation of the Upper Mantle

Work on this project in the past years has found that (1) the upper crust is not a simple layered model but consists of a velocity gradient from approximately 4 km/s to approximately 6.9 km/s over the crustal section; (2) the observed thickening of the crust is due to the formation of a low velocity zone, at the base of the crust, that thickens with age and may be composed of serpentinized mantle material; (3) the upper mantle velocity is azimuthally dependent near the rise crest and the degree of anisotropy decreases with age over the plate; (4) a low velocity zone on the upper mantle near the rise crest and in the area of our study extends laterally up to 150 km east of the rise crest. As a result of these findings, the upper crustal structure and nature of the velocity gradient, as well as the age and spatial variations in the crustal structure and the observed crustal thickening, are being examined in greater detail. We also hope to use arrivals from the horizontal geophones in the ocean bottom seismometers to determine the shear velocity structure of the oceanic crust and upper mantle. These studies are continuing on the Juan de Fuca Ridge and the East Pacific Rise between 12° and 15°N. (Lewis, Bond; [K. McClain, Hegdal, Thomson, Department of Geophysics])

A Seismic Refraction Study of the Kodiak Shelf, Gulf of Alaska

Reconnaissance seismic refraction (sonobuoy) data suggest that the present day Kodiak shelf is underlain by an ancient shelf-break structural high that formed during late Paleogene through middle Neogene time. In two large areas of the shelf, beneath Albatross and Stevenson basins, the old structural high was abandoned in late Miocene time when the present day shelf break structures began to grow on the slope about 45 km seaward of this older trend. In the central area of the shelf, the old structure underlies a zone containing numerous reverse faults; this central shelf structure may have resulted from rejuvenation of the old shelf-break high. (Holmes, McCulloh [J.L. Johnson])

Sonobuoy Refraction Measurements from Norton Basin, Northern Bering Sea

Recent discovery of thermogenic gaseous hydrocarbons seeping from the sea floor 45 km south of Nome, Alaska, suggests that the underlying Norton Basin may be an important future petroleum province. The results of 38 sonobuoy refraction profiles obtained in 1977 and 1978 show that Norton Sound and Chirikov Basin are underlain by a large sedimentary trough approximately 130 km wide and 350 km long; the basin extends northwest from Stuart Island to a point 100 km west-southwest of King Island. Although average depth to basement is only 2.5 km, two deeper troughs, containing up to 4.5 km of sedimentary section, were discovered 75-90 km northwest of the Yukon River Delta. Compressional velocities can be used to distinguish four major units filling the Norton Basin; the ages of these rock range from Upper Cretaceous to Neogene. The wide range of basement velocities (4.5 to 6.9 km/sec) indicate that the sedimentary fill is resting on a complex of Paleozoic and Mesozoic igneous, metamorphic, and sedimentary rocks similar to those mapped on Seward Peninsula and St. Lawrence Island. (Holmes, McCulloh [J.L. Johnson])

Geophysical Researches on the Nature of the Ocean Floor

An unusually thorough, interdisciplinary analysis of the large ONR refraction experiment off the Queen Charlotte Islands in 1974 is continuing. Starting with the Ocean Bottom Seismometers themselves, the signal distortions introduced by direct magnetic tape recording and playback have been investigated and removed. The computer operating system to generate calibrated three-component record sections for amplitude comparisons and late arrival identification is being revised. Substantial efforts are being made to understand the regional basement and sediment structure so that the scatter in the arrival times can be reduced. Heat flow measurements along one of the refraction lines are being analyzed to test the effect of varying crustal temperatures on section velocities. Overall, we believe this is the first refraction experiment to receive a full interdisciplinary investigation of all probable causes of acoustic variations.

Research continues in the same general line -- an attempt to understand an important physical process that must influence the seismic results and yet has been neglected in prior studies. The phenomenon is diffraction, a process that has observable effects whenever propagation structures are comparable in size to a wavelength. In contrast to interference, the effects of diffraction cannot be modeled in any way by ray theory, and current computer methods are both clumsy and expensive. A mercury surface-wave tank to model the effects of (P-wave) diffraction on propagation in a velocity-layered space is being built in order to construct fully diffractive record sections for chosen structures. Interesting anomalies in the structures and in the frequency content of arrivals have been documented. (Lister [Wade])

Trench Tectonics

Three pieces of the circum-Pacific trench system were investigated with the aim of discovering and comparing evidence of tectonic motion. The areas were selected to give the best chance of observing such motion, and the research was conducted both on the University vessel R/V *Thomas G. Thompson* and on vessels provided by a foreign cooperating organization in New Zealand. The

principal technique was acoustic reflection profiling, a method of low frequency echosounding that outlines both the thickness and structure of sea-floor sediments. Measurements of the geothermal heat-flux were also made, since it is affected by the sedimentation processes known to occur in ocean trenches.

All field data have been reduced and compiled; final results are still in preparation. (Lister)

Convection in a Porous Medium at High Rayleigh Number and Its Geothermal Implications

A unique facility to study convection in a porous medium (gravel bed) under rigorous conditions is being constructed. Present data are inconsistent and unsatisfactory for analysis of important natural geothermal systems. If the facility is successful, it will be possible to fill in an important gap in fundamental knowledge, advance the theory of the subject, and begin the application of realistic data to the investigation of geothermal circulation.

Detailed cell design has nearly been completed, and construction of some parts has begun. (Lister; J.R. Booker [Gibson], Department of Geophysics)

Determining the Thermal State of Old Oceanic Crust and Lithosphere

Two special new heat flow instruments optimized for making accurate measurements in old ocean basins are being constructed. This is part of a joint field project with M.I.T. to establish the feasibility of obtaining 'reliable' heat flow means for old lithosphere. The designs follow on the successful prototype digital telemetering probe tested in 1976, where solutions of the problems of full digital telemetry, indefinite multipenetration mechanical life, and repetitive in situ conductivity measurements were demonstrated. The heat flow problem is one of the two most important outstanding today, and the instruments will be ideal also for future work on hydrothermal circulation in the ridge environment -- the other issue. The prototype was tested successfully on a cruise of R/V *Wecoma* to Cascadia Basin.

The 150-odd thermal gradient measurements extend from near the crest of the Juan de Fuca Ridge to near the margin of the continent. Seismic reflection profiles were obtained to aid in the interpretation of the data. Supplemental funds have been requested to finish the second instrument and make necessary modifications. (Lister, R. Johnson [Mojesky, Department of Geophysics])

Volcanic Volatiles

The past year has seen considerable progress in studies of volatile fluxes from the earth's mantle to the surface along zones of active volcanism. The principal approach has been to develop microprobe techniques to measure trace quantities of carbon (electron microprobe) and hydrogen (ion microprobe), on a microscale, in silicate glasses trapped within crystalline phases from subalkaline and calcalkaline volcanic suites. The newly developed microprobe capabilities will provide a refined perception of the distribution, abundance, and mobility of carbon dioxide and water in preeruptive igneous systems. Other studies include a survey of volatile abundances in basalts from fast and slow spreading ridges and a study of the diffusivity of water in silicate melts as a function of pressure, temperature, and the fugacity of water. (Delaney; I.S. McCallum, E.A. Mathez, Department of Geological Sciences)

Hydrothermal Activity Associated with Spreading Centers

The Iceland Research Drilling Project (Summer, 1978) produced a continuous 2 km core of plateau basalts which have been progressively metamorphosed. These samples are being examined for variations of secondary sulfides, quartz, carbonates, zeolites, and other vein materials. Of particular interest are the well-developed fluid inclusions in the vein materials that provide a basis for paleotemperature measurements in an inactive geothermal field which formed at an active spreading center. (See also p. 32.) (Delaney, Christensen, H.P. Johnson)

A bottom photography and dredging program at the intersection of the Kane Fracture Zone and the Mid-Atlantic Ridge was conducted during November 1977 and October 1978. These studies are preliminary to a series of submarine *Alvin* dives in 1980 which will examine for the first time the intersection of an active ridge and a spreading center. A remarkable set of hydrothermal quartz veins and breccia samples was recovered from the intersection in 1978 and will form a valuable comparative suite with the altered Icelandic basalts. (Delaney; W.B. Bryan, G. Thompson, and H. Dick, Woods Hole Oceanographic Institution)

A Paleomagnetic, Rock Magnetic, and Opaque Mineralogy Study of Drill Cores from the Mid-Atlantic Ridge (DSDP Leg 45)

An intensive study of the rock magnetic properties and opaque mineralogy of the igneous rock samples from the three DSDP drill holes in the flanks of the Mid-Atlantic Ridge at 23°N is being carried out. The objectives are to determine the origin and evolution of the magnetic properties of the igneous oceanic crust and the contributions of various sections of this crust to the marine linear magnetic anomaly pattern.

Paleomagnetic studies of the basalt samples of Mid-Atlantic Ridge recovered during DSDP Leg 45 have led to a revision of the current view that the oceanic igneous crust is a recorder of geomagnetic field reversals. The discovery of several magnetic polarity reversals with depth in the crust has indicated that oceanic igneous basement should not necessarily be considered magnetized uniformly in direction, or even polarity, in a given vertical cross section. Statistical arguments indicate that magnetic reversals with depth are to be expected in typical ocean crust, but also that this does not conflict with current theories of plate tectonics or exclude the upper layers of the crust from making a major contribution to the overlying linear magnetic anomalies. Certain ratios of average crustal-formation time to average polarity interval may be responsible for the reduced amplitude of magnetic anomalies in some areas. The studies are continuing. (H.P. Johnson)

Volcanic-Tectonic Evolution of Rifted Mid-Ocean Ridges (Neo FAMOUS)

An intensive study of a section of the Mid-Atlantic Ridge has been carried out. This project is centered around two major problems that arose during previous studies of the Mid-Atlantic Ridge (project FAMOUS). The first problem concerns the evolution of rifted oceanic ridges: how these rifts change shape with time and what this implies for magmatic and tectonic processes. The second problem concerns the apparently common occurrence of reversely magnetized rocks in the center of the rift valley where current theories predict only

normally magnetized crust. The use of magnetic properties of oceanic rocks as indicators of hydrothermal activities will also be investigated.

The field studies took place during the summer of 1978 using the surface ships, R/V *Gillis* and R/V *Lulu*, and the submersible DSRV *Alvin*. Large areas of two very different types of median valley floor were mapped and sampled in great detail. Preliminary analyses of the data indicate that these areas (Narrowgate and AMAR valleys) are substantially different from the median valleys that have been studied previously. (H.P. Johnson)

PHYSICAL OCEANOGRAPHY

Global Climate Modeling with Particular Reference to the Role of the Oceans

Work on global energy-balanced models of the Budyko-Sellers type, with separate consideration of the ocean, has been continuing. The most advanced model includes vertical ocean-atmosphere exchange, meridional (diffusive) exchange in atmosphere and ocean, zonal advective exchange between air over ocean and land, and permanent and seasonal ice over ocean and land. Latent heat is included in the heat budget, and precipitation has a prescribed latitudinal shape function.

The model can describe present global temperature distribution reasonably well. Prediction of climatic changes due to changing solar constant indicates a moderating effect of the ocean, with less risk for "run-away" climatic changes. (Welander, Temkin [Liu])

Theory of Ocean Circulation, with an Ideal Fluid Interior

A closed ocean circulation model, with (potential) density conserved below a top mixed layer, has been formulated. Analytical and preliminary numerical experiments indicate that such a model, which has some support from the recent " β -spiral" studies by Stommel and Schott, must develop interior fronts and insulated pools of deep water. Therefore, a small diffusion effect will have to be added. Numerical calculations for such a model involve many difficulties, similar to those found in the theory of shocks, and further development of the numerical technique for the problem will be needed before an eventual complete solution can be found. (Welander)

Arctic Sea-Air Interaction

The most significant phenomenon resulting from the interaction of the ocean and atmosphere in polar regions is the formation of sea ice. In order to arrive at a quantitative understanding of this interaction, two major sets of problems are being investigated: The first pertains to the environment in which arctic sea ice exists, and the second deals with the properties and behavior of the ice itself. Individual studies have been designed to answer specific questions regarding the regional heat and mass balance of the ice pack, forecasting of ice growth in areas of seasonal and perennial ice, lateral melting in leads, effects of inhomogeneities on the scattering and absorption of radiation in ice, infrared albedos of polar ice and snow, pressure ridge decay, sea ice formation and growth in a wave field, and wave-induced heat transfer to an ice wall.

At present, we are carrying out laboratory and field studies of iceberg decay, and laboratory studies of wave damping by sea ice. (Martin, Kauffman [Bauer]; G. A. Maykut, Department of Atmospheric Sciences)

Bering Sea Ice Studies

The objective of this project is to model the small-scale response of the Bering Sea ice edge to changes in atmospheric circulation. Instruments of various NOAA and NASA satellites, namely the Advanced Very High Resolution

Radiometer (AVHRR) on the TIROS-N satellite and the Scanning Microwave Multi-channel Radiometer (SMMR) on the NIMBUS-G satellite and, for detail, LANDSAT imagery, will be used. In February-March 1979, a ship and aircraft experiment will be conducted to gather surface truth data for the satellite observations. The satellite data will be analyzed by prior arrangement at the computer center of the NOAA/Pacific Marine Environmental Laboratory. Some of the tapes from the SEASAT altimeter also may be analyzed to study its response to regions of heavy ice ridging in the Beaufort Sea. (Martin)

The properties of the sea ice at the edge of the Bering Sea ice cover will be investigated in February 1979 in order to relate the small-scale ice properties to satellite images obtained simultaneously from the NIMBUS satellite. In particular, ice thickness, salinity, and temperature, as well as certain surface properties related to microwave emissivity, will be measured at various stations on the ice that can be reached by helicopter from the NOAA ship SURVEYOR. (Martin, Kauffman)

ISOS: Transport Measurements of the Antarctic Circumpolar Current

International Southern Ocean Studies (ISOS) is a program of dynamics and monitoring experiments in the southern ocean. The objective is the understanding of the long-term, large-scale variability of dynamic processes and the interaction of the southern ocean with the global oceanic and atmospheric circulation. This IDOE/NSF program is managed jointly by the University of Washington and Texas A&M University, with more than 15 national and international institutes participating.

As part of this program, moored instruments were designed and deployed across Drake Passage to monitor deep ocean pressure fluctuations that are associated with the Antarctic Current System. The mooring project began in 1976 and will continue through 1979. In the past year, two instruments were recovered after year long deployments and four new instruments were deployed. The recovered data, which are of high quality, are being analyzed. Preparations are presently underway for a major field program during 1979. We will also collaborate on data analysis and interpretation of the ISOS RIDGE experiment with scientists from Oregon State University, Woods Hole Oceanographic Institution, and the New Zealand Oceanographic Institute. (D.J. Baker, Wearn; A.M. Pederson, Applied Physics Laboratory)

Statistical Theoretical Methods in Ocean Dynamics

This research concerns development and application of theoretical methods of statistical hydromechanics for problems of ocean dynamics. Present and proposed research include: (1) the effect of irregular topography on statistics of ocean currents; (2) Rossby wave interactions; (3) mixing of passive chemical contaminants by mesoscale eddies; (4) energetics of internal inertial-gravity wave interactions; and (5) an area of proposed research - a study of theoretical predictability times in models of weather/climate dynamics. In each area of research, high resolution numerical flow simulations are used both to explore specific flow realization and to provide data for testing statistical theoretical predictions.

Theories have been devised that predict the spectral evolution of nonlinear Rossby waves and of nonlinear barotropic eddies interacting with irregular bottom topography. Predictions have agreed with results of numerical flow simulations for cases of relative nonlinearity ranging from zero (linearized equations)

to full turbulence. These theories have been extended to include interaction of mesoscale eddy statistics with large scale mean circulation. A more general connection between theories of weak, resonant wave interaction and theories of strong turbulence has been presented. The oceanic internal wave field has been demonstrated to be neither very weakly nor very strongly interacting. (Holloway)

Studies in Marine Hydrodynamics

The following topics are being investigated:

- 1) bathymetric effects on the wind-driven and thermohaline circulation of the ocean;
- 2) the dynamics of the upper layer fjord circulation;
- 3) lateral circulations in relatively narrow estuaries.

The results thus far are as follows:

A new formulation for the effect of bathymetry on the baroclinic ocean circulation has been used to show a mechanism for the formation of strong currents along the flanks of a mid-ocean ridge and for the presence of strong currents and countercurrents along a continental slope at the western side of the basin. This new formulation did not reproduce the localized sinking at the northern extremity of the eastern boundary that had been obtained in some numerical ocean circulation models. It is suggested that the numerical results were caused by unrealistic surface boundary conditions causing a localized vertical instability in the density field.

A jet flowing eastward over an abrupt depth change has been shown to experience a broadening or a narrowing upon entering a shallower or deeper region, respectively. Downstream waves occur with the vorticity along a streamline oscillating between relative and planetary components. Contrary to the case of a uniform current, the relative vorticity variation along a streamline includes the effect of current shear variations as well as streamline curvature. In particular, the central streamline also experiences a significant oscillation in the shear component of relative vorticity.

A comprehensive investigation into the lateral and vertical circulation components of the net salt flux in a class one or two estuary has demonstrated that results previously reported in the literature are sensitive to arbitrary changes in the partitioning of the estuary cross section. Recognition of the dominant importance of the gravitational potential provides a unique partitioning that maximizes the variance into the vertical component of circulation for most cases where the local curvature of the estuary is not too great nor the estuary too shallow.

A new, eddy-coefficient independent expression has been obtained whereby the estuarine distribution of nonconservative quantities can be determined from the longitudinal salinity distribution, the river inflow, the estuarine geometry, and the uptake rate. (Rattray, Dworski [Miyamoto, Shetye])

Nonlinear Interactions for Internal Gravity Waves and Barotropic Rossby Waves at Midlatitudes

Some of the most important results of this study are:

- 1) A simple and more exact development of the theory, avoiding

the use of the perturbation schemes that have been reported in the literature.

- 2) An estimation of nonlinear time scales for systems with initially few components of any amplitude. This result gives a measure of the importance of nonlinear effects relative to the linear ones.
- 3) The solution of the three-wave problem. This is a first step in understanding the dynamics of the nonlinear problem for the weak interactions regime.
- 4) The same method has been used to develop a theory of nonlinear interactions in the equatorial β -plane.

Some of the results show many similarities with the systems studied before (like the existence of the pseudomomentum as an integral of motion). Some other results, however, are properties of this new system (like the steepening of Kelvin waves). A preliminary paper has been published. (Ripa)

Theoretical Studies of Mesoscale Oceanic Processes

Theoretical studies of mesoscale eddies with the purpose of understanding (a) vorticity mixing in the oceans and (b) dynamics of eddies imbedded in strong currents, particularly in the equatorial region, are being carried out. Preliminary numerical studies in case (a) indicate that vorticity mixing is very difficult to achieve in a two-dimensional ocean circulation, due to strong restoring forces from the so-called β -effect. Further work is needed to clarify this point. Theoretical predictions have been obtained in case (b) showing a possible breakdown of classical quasi-geostrophic theory in this regime, with fully three-dimensional, nonisotropic eddies. Tests of the theory will be attempted, using existing and forthcoming data from the equatorial Pacific, in collaboration with Dr. D. Halpern. (Welander [Gross])

Depth Variability of Meridional Gradients in the Western Pacific

A statistical investigation is made of the variability of meridional temperature, salinity, and sound velocity gradients with depth and longitude in the western Pacific. A spectral analysis of the gradients in the wave-number range between 0 and 13.4 cycles per 1000 km (c.p. 1000 km) shows that the shape of the spectra depends strongly on depth and less so on longitude. In the upper 150 m, the shape is irregular. Between 300 and 600 m the spectra show a well-defined peak between 1.5 and 3.3 c.p. 1000 km and a sharp drop-off in energy beyond 10 c.p. 1000 km -- features that are compatible with baroclinic Rossby waves. Meridional gradients at the sea surface are coherent with those in the upper 150 m and incoherent with those below. Meridional gradients at 300 m are coherent with those at greater depths. The depth dependence of the spectra and coherence is attributed to different processes of gradient formation in the upper and lower layers of the sea. (Roden)

Fronts of the Central Pacific

The relationship between ocean fronts and atmospheric forcing is being investigated. It has been determined that fronts will intensify and develop where there is an imbalance between gradients of temperature and salinity balance on the one hand and gradients of heat and salt flux divergence on the other. Fronts near the sea surface are strongly influenced by the horizontal

shear of the wind, which produces convergence in the Ekman transport. A simple prognostic model based on Ekman dynamics and available satellite sea surface temperature and wind data is used to estimate rates of frontogenesis and frontolysis in the central and western Pacific. The computed patterns and rates have been compared to those sensed by satellite. In the subtropical region, frontogenetic and frontolytic bands tend to occur in pairs, an occurrence which is attributed to the wind stress maximum over the area. Typical observed frontogenetic rates are 0.5-1 C/100 km per week. The computed rates underestimate the observed ones by 25-50%. (Roden)

Geothermal Transport and Water Characteristics of the Central Pacific Equatorial Current System along 150° W

During late 1977 a NORPAX field program to study fluctuations of the equatorial current system in the central Pacific along 150°W was conducted. One element of this program was to measure the density field across the current system by means of shipboard CTD profiles. The time variations in the geostrophic transport will be compared to directly measured currents and sea level indices of surface transport.

Vertical sections of temperature, salinity, and geostrophic velocity from four cruises have been drawn. Cold-core eddies that are prominent in the North Equatorial Current are not evident in the South Equatorial Current with respect to transport. The most variable component of the current system is the South Equatorial Current. Comparison of transports computed from direct current measurements in the North Equatorial Countercurrent and geostrophic transports relative to 1000 db indicate agreement within 10%. Comparison of transports computed from CTD profiles and AxBTs (airplane dropped) indicates that there is a very high correlation except where the deep expression of the North Equatorial Countercurrent occurs. (Taft, Kovala)

Density Measurements in a POLYMODE Local Dynamics Experiment

A major component of the POLYMODE Local Dynamics Experiment (LDE) is density profiling to 3000 db. The potential vorticity equation will be used to analyze the dynamics of the eddy field. The density measurements provide estimates of the geostrophic velocity shear which are combined with direct measurements of velocity from SOFAR floats and moorings to compute the absolute velocity profile. The dynamics of the eddy field are to be analyzed through use of the potential vorticity equation.

In order to provide a climatological background for the LDE, the historical data from the western North Atlantic have been analyzed. The increase in eddy energy toward the Gulf Stream is associated with the southern boundary of the Gulf Stream return flow. In a climatological sense the LDE was carried out within the return flow. From May 15 - July 15 1978, the R/V *Gyre* and R/V *Iselin* were used to carry out seven surveys of the eddy field at 31°N 70°W. The overall eddy energy increased by a factor of two during the period. Small-scale eddies were resolved both in the upper thermocline and in the deep water below the thermocline. Maps of geostrophic stream function and of salinity and oxygen on potential density surfaces are being prepared. In late 1979, when the velocity data become available, the density data will be integrated with the directly measured velocities and the dynamical analysis will be undertaken. (Taft [Lindstrom]; J.C. McWilliams, National Center for Atmospheric Research)

Climatically Related Arctic Ocean Studies

Continuing studies of the West Spitsbergen Current and the transformation of Atlantic water north of Spitsbergen; measurements in the East Greenland Current; deep observations in the Polar Basin; tracer profiles in the mixed layer; the outflow of deep water from the Greenland Sea; and a synoptic inventory, with moored time series, of the Eurasian Basin will be undertaken in the next three years.

Heat transport via the West Spitsbergen Current is by far the largest oceanic component of the Arctic Ocean heat budget, appears to be important climatically, and has a large variability on long time scales. A set of measurements undertaken in the West Spitsbergen Current in 1976-77 is aimed at determining the spatial scales of the flow. This is preliminary to the detailed transport studies planned for the Polar Sub-Programme of GARP, likely to begin in 1979. In order to fill the two-year data gap extending from 1977-79, four current meters (with temperature sensors) were deployed in 1977 and two in 1978; these were located in the core of the current at 79°N. Their primary role is to achieve continuous current and temperature time series extending from 1976 into the early 1980's. Analysis of the 1977-78 time series is underway. Present plans are to extend the current measurements to 1980 by insertion of a new mooring in fall 1979. Deep moorings in the Polar Basin are scheduled for deployment in March and in the East Greenland Current in April. Planning is continuing for the other studies mentioned above, all of which are cooperative with other laboratories and institutions. (Aagaard, Tripp, Darnall, Harding [Hanzlick])

Seasonal Processes in the Iceland Sea

Between 1974 and 1976 a sequence of four seasonally distributed STD cruises in the Iceland Sea was conducted, and long-term moored current and temperature measurements were made in the Denmark Strait overflow. The work was designed to study such questions as the origin, modification, and outflow of the intermediate and deep waters; the mechanisms involved in the seasonal budgets of salt and heat; the climatic role of the East Greenland Current; the important time scales in the overflow and their origin; and possible secular changes in the overflow water characteristics.

Vertical hydrographic trends in the deep northwest Atlantic differ markedly from those in Denmark Strait and within the Iceland and Greenland seas. Arctic Bottom Water ($\theta < 0^{\circ}\text{C}$, $S = 34.92$ ‰, tritium < 2.5 T.U.), the densest water type found in the arctic seas and at the Denmark Strait sill, contributes in only a very minor and intermittent fashion to the overflow through Denmark Strait. Instead, the principal dense component of this overflow is an intermediate water of arctic origin, at about 34.87 ‰ and $4-5$ T.U.; it is formed in winter at the surface north of Iceland. By virtue of its rather close and immediate coupling with the sea surface north of Iceland, the deep North Atlantic must be more sensitive to climatological and ecological perturbations than hitherto believed.

Downstream from the sill, the Denmark Strait overflow is composed of a strong mean flow of about 1 knot, upon which are superimposed various low-frequency variations. The mean flow is driven from an upstream reservoir of nearly constant density and pressure head. This flow is baroclinic and increases with depth; it is directed nearly along the isobaths. A frictional

boundary layer extends at least 25 m from the bottom. Modulations of the mean flow on time scales of weeks to months are random and do not exceed about 20%; there is, for example, no seasonal modulation. By far the largest of the low-frequency variations is a persistent signal with a time scale of 1.5-2.5 days and an amplitude comparable to the mean flow that represents a baroclinic instability. The statistics of this instability band are highly nonstationary, however. Other fluctuations include those of synoptic meteorological time scales and of tides; there is apparently no inertial signal. (Aagaard, Tripp [J.H. Swift])

Current Measurements in Possible Dispersal Regions of the Beaufort Sea

The dispersion mechanisms and circulation over the Beaufort Sea shelf is being investigated. The field work involves the deployment and retrieval of moored instruments through the ice. The principal objectives are: (1) to obtain two year long time series of current and temperature over a portion of the shelf that appears to have a very strong and variable flow (such an area would be expected to be a very effective dispersal region), and (2) farther in on the shelf, to try to bridge the outer active and the inner quiescent (at least in winter) region.

Preliminary analysis of current time series indicates that the outer shelf regime extends landward to at least the 100 m isobath. The flooding of the outer shelf for long periods of time by Atlantic water is particularly noteworthy. Moorings are scheduled for deployment in February 1979. (Aagaard, Tripp, Darnall, Harding)

Collaborative Research in the Poleward Undercurrent along the Continental Slope off Oregon

The seasonal variability of the poleward undercurrent on the continental slope off Oregon is being studied. A cross-shelf and slope array of current meter moorings has been maintained for a year, and periodic hydrographic surveys have been made along the array line. The data obtained are being analyzed in an attempt to better understand the relationship of the poleward flow to shelf currents and to the Eastern Boundary Current System. This project also includes studies of the entire California Current System using existing data.

Results from the field program are not yet available. Studies using existing data have been published and include many interesting results. At each latitude along the West Coast, the current system has a coastal flow and an offshore flow, the California Current. The seasonal variation of the California Current appears to be related to the curl of the wind stress. The seasonal variation of the nearshore flow is related to wind stress at the coast. At many latitudes, a northward mean is also imposed on the flows nearshore. This mean could be related to the local curl of the wind stress or to topographic effects. Research is continuing in these areas. (Hickey, Beck, Ripley, Geier [Pola])

Small-Scale Mixing and Finestructure

Studies designed to develop an understanding of the dissipative processes in the ocean and their role in the large-scale, time-averaged budgets of heat,

salt, and momentum are continuing. There are two phases of the project: an assessment of the levels of small-scale (centimeter) mixing in the upper ocean and the evolution of intrusive water bodies. The intrusions have vertical scales of from 1 m to tens of meters and horizontal scales up to tens of kilometers. They appear to be major factors in the heat and salt fluxes of the ocean and in short range sound speed anomalies.

Many parts of the microstructure and towed body data taken during MILE have been analyzed. To complete the microstructure study the dynamic response of thermistors is being extensively tested. Measurements taken simultaneously with Sanford's shear profiles during POLYMODE are partially analyzed.

The results of these studies so far are:

- 1) A new method for measuring the vertical velocity of internal waves was developed.
- 2) Strong evidence for mixing adjacent to the island of Bermuda was found and nearly adiabatic step-like features are associated with the mixing.
- 3) The dominant microstructure activity in the Gulf Stream was found to be associated with double diffusivity activity on the boundaries of thermohaline intrusions. Gradient flux mixing was relatively weak -- implying moderate-to-low levels of turbulent mixing.
- 4) Algorithms for estimating the rms noise in N^2 , Ri , dynamic topography and maps on density surfaces were developed. (Gregg)

Oceanic Boundary Layers

Linear fluctuation theory is proposed for theoretically studying the structure and maintenance of unsteady motions within the turbulent Ekman boundary layer with applications for understanding behavior of both upper and bottom geophysical boundary layers. In addition, establishment of the general stability characteristics for laminar Ekman layers will be made so that specific initial-value problems can be investigated.

Initial-value problems in the laminar Ekman layer have been solved in a general fashion by numerically inverting Fourier transforms. Results reveal that wave packets contain different modes because of origin of instabilities. Turbulent Ekman layer has been synthesized and investigated for stability. It appears that only dynamic modes can be destabilizing (inflexion points). (Criminale [Spooner]; Dr. M. Gaster, National Physical Laboratory, Teddington, England)

Fluctuations in Geophysical and Boundary Layer Flows

Studies related to atmospheric boundary layers and turbulence in stratified shear flows are continuing, and investigations required to complete details of a new method for solving stability problems (related to characteristic solutions) for parallel and almost parallel shear flows are being initiated.

Stratified shear layer fluctuations have been studied as initial-value problems and by spatial Laplace transforms (together with analogue computer).

Asymptotics are known by general dispersion relation. Oscillations in boundary layers are examined by two-scale perturbations. (Criminale [Bradt, Pinte-Plasencia]; J. Kevorkian, Department of Aeronautics and Astronautics)

Time Dependent Turbulent Boundary Layers in Tidal Flows

The importance of a time varying current on the Reynolds stress profile is being evaluated. By using an array of ten 3-axis current meters in the lowest 'log layer,' the mean flow structure and low frequency stress distribution may be continuously recorded over complete tidal cycles in order to investigate possible hysteresis effects in unsteady turbulence structure. Dissipation rates, distribution characteristics, and structure functions will be evaluated. The low frequency sensors, instrument platform, and data acquisition system, which were developed by J.D. Smith, will be used in the proposed research, with the participation of Dr. Smith. Previously, a similar high frequency sensor was used in ocean microstructure studies and in natural fluvial boundaries.

Preliminary investigations at the field site (Skagit Bay) were undertaken in December 1978. Detailed profiles of bed topography at and around the site were constructed, and the large scale structure of the flow was examined. This will provide the necessary morphological and fluid dynamic setting for the detailed measurements. (Nowell, J.D. Smith)

Circulation and Exchange Processes

Puget Sound presents an excellent opportunity to examine the physical dynamics of a fjord-type estuary characterized by freshwater input along its entire length. Research supported in part by the MESA Project is oriented toward understanding the sound's ability to accommodate discharged waste water without producing onerous consequences. One research emphasis has been understanding the processes of bottom water renewal and mixing over sills which contribute to the effective flushing in the sound. This work has been carried out by the Pacific Marine Environmental Laboratory's Coastal Physics Group.

Analysis of velocity, temperature, and conductivity measurements from a vertical array of sensors in Puget Sound during 1975-76 showed that most dense bottom water entered the sound below sill depth at about fortnightly intervals associated with large tides over the entrance sill. Maximum observed current speeds implied excursions exceeding the length of the sound in five days, and consequent renewal of deep water in about two weeks. During 1977, observations were made along the sound and in the Narrows, a shallow constriction at the head of the main basin connecting it to the southern basin of Puget Sound. The result was a description of the effect of flow through the Narrows on the movement of deep water through the main basin. Observations were made along the sound and in Admiralty Inlet, the entrance sill to Puget Sound, from summer through fall to describe further mixing processes over the sill resulting in new deep water entering the sound.

Subsequently, the study was extended to Knight Inlet in British Columbia, a fjord-type estuary in which freshwater is added primarily at the head of the inlet. Contrasting the two fjords will help in determining how the position of freshwater input to the estuary affects circulation. The first experiment in this series was carried out jointly with Canadian and University of Washington

oceanographers during summer 1977. The Coastal Physics Group made observations of flow and water properties at and below sill depth at a number of locations landward of the inlet sill. These data are being analyzed.

The Strait of Juan de Fuca acts as source water for bottom inflow to Puget Sound. Understanding the dynamics that control circulation in the strait therefore contributes to the Puget Sound research as well as providing a background for analysis of the risks associated with oil transport in the strait. In conjunction with the Pacific Marine Environmental Laboratory Deep Sea Physics Group, a research program began in 1975 with field activities in the western Strait of Juan de Fuca. Two major field experiments conducted during FY77 verified the dominant influence played by Pacific storms in reversing estuarine flow, particularly during winter months. For the eastern Strait of Juan de Fuca, historical data have been analyzed revealing a large variability in local currents. Based on these results an extensive field program has been planned to determine the seasonal change in circulation and the influence of weather on tide-dependent currents. During FY 78 analysis of data continued, and efforts were focused on synthesizing the research results from the Strait of Juan de Fuca into a technical report to provide background for ocean policy decisions. (Cannon)

Turbulent Mixing in Estuarine Waters

In recent investigations of mixing in highly stratified estuaries we have found that internal hydraulic processes, including the production and dissipation of nonlinear internal waves, are of critical importance. Our first efforts concerned the mixing mechanisms in salt wedge estuaries and focused on the nearby Duwamish River. More recently, the main emphasis has been on mixing in fjords along coasts with large tidal ranges and in particular on Knight Inlet in British Columbia. The innovative experimental techniques that were developed for use in the Arctic mixed layer and in the Duwamish River are now being employed in Knight Inlet. These are based on an automatically cycling velocity and density profiling system and on a ship mounted mast supporting a number of velocity component measuring current meters plus five pairs of temperature and conductivity cells. Each of the sensors is interfaced, along with a precision microwave navigation system, to a NOVA 1200 computer. In addition, a high frequency echo sounder capable of resolving layering in the interior of the water column, thus yielding information on the spatial and temporal structure of internal wave fields, is now a critical part of the overall system.

Entrainment of seawater into the surface layer of the Duwamish River has been found to occur impulsively during the ebb. At this time the reach of the estuary in which the mixing occurs attains its critical internal Froude number and the internal wave field grows in amplitude until it produces sufficient turbulence to destabilize the pycnocline, causing the surface layer to rise rapidly in salinity and deepen. Although internal hydraulic processes also are important in Knight Inlet, they are of a different character. Here the primary mixing events occur at an inner sill around which several types of flow instabilities are found. During normal and spring tides, flow over the sill becomes supercritical and an internal hydraulic jump develops. During times of neap tides, lee waves form downstream of the sill. Both first and second mode nonlinear internal waves form in regions of strong shear associated with the major flow features. Also large amplitude second mode internal waves form with the breakdown of both the supercritical flow region and the lee waves as the tidal

current slackens. These waves then propagate up-inlet and cause mixing in regions remote from their source.

Future work in the Duwamish River will involve characterization of the mechanisms by which energy is extracted from the internal wave field and used to increase the salinity of the surface layer. Additional work in Knight Inlet will include quantification of the above mentioned internal hydraulic processes and the development of theories to evaluate the amount of mixing that is produced by each of these. Also it will involve examination of the flow and density fields in the highly stratified region near the head of the inlet. (J.D. Smith, Paul, Lee)

Two-Layer Analysis of Steady Circulation in Stratified Fjords

In deep, narrow, fjord-type inlets with copious runoff near the head, freshwater inflow produces a surface slope and a pressure gradient that drives a brackish, near-surface layer seaward; at greater depths a denser, saline layer derived from oceanic water moves landward. We have developed a self-consistent two-layer representation of this mode of inlet flow, generally referred to as "estuarine circulation." The approach is different from other layered analyses in that the present model includes important effects of variations in mass density, channel width and depth, and also allows for turbulent and advective exchange between the deep and near-surface layers. The starting point of the analysis is a set of equations expressing incompressibility and conservation of mass and horizontal momentum in each zone. Transfer of mass and momentum across the interface between the layers is parameterized by two interzonal exchange flux rates, F_u and F_d , representing the upward and downward rate of fluid flow per square meter of interfacial area. When the time-averaged mass density variations can be estimated from field data, then the flux rates, F_u and F_d , can be inferred entirely from known or measurable quantities. Two integrals of the motion are immediately available, and the mathematical problem is reduced to solving a pair of nonlinear equations for the layer cross-sectional areas. By way of illustration, the procedure is applied to Knight Inlet, a deep, stratified fjord on the Pacific Northwest coastline.

In addition, the method was applied to estuarine circulation throughout a portion of the deep inlet system near Kitimat, British Columbia. The channel system consists principally of two major passage ways which are interconnected, and which therefore have interdependent estuarine flow. One begins at its landward end with Kitimat Arm and continues as Douglas Channel, with Kildala Arm as a side channel of Kitimat Arm. The most landward segment of the other major passageway is the deep, remote fjord called Gardner Canal which continues ultimately as Verney Passage, the latter dividing to form Ursula Passage to the south of Gribell Island. These two major passageways are connected near their landward ends by Devastation Channel which bounds Hawkesbury Island on its eastern side.

The overall objective of this phase of the project was to construct a numerical model capable of representing the major features of estuarine circulation throughout the network. Water movement in deep and narrow inlets such as those considered here is generally characterized by two modes: tidal motion and estuarine circulation. The estuarine circulation mode is usually assumed to be superimposed on the tidal motion, and that assumption was made in the present analysis. However, flow features associated with the interaction of tides

and inlet bathymetry have an important influence on density distribution, which in turn is an important factor in estuarine circulation.

If a pollutant is introduced at a steady rate into a local segment of one of the inlet components, then as a consequence of upward and downward mixing, as well as horizontal advection, estuarine circulation will distribute the polluting substance throughout the entire inlet network. The steady-state distribution of a hypothetical polluting substance was determined numerically from the results of the present model. Specifically, it was assumed that the polluting source was localized in the upper layer of Douglas Channel (i.e., near the seaward end of the network). The calculation illustrated the fact that estuarine circulation tends to distribute dissolved and/or suspended substances throughout the entire network. Moreover, the less stratified the system, the greater the concentrations of pollutant in distant reaches of the system. (Winter; C.E. Pearson, Department of Aeronautics and Astronautics)

Finite Element Computation of the Barotropic Tides in Knight Inlet, British Columbia

In the recent past, Pearson and Winter developed a new numerical procedure for computing periodic tidal motion in deep estuaries with complex shorelines and irregular bathymetric configurations. The starting point of the analysis is the standard set of vertically-integrated, time-dependent equations expressing conservation of horizontal momentum and mass in two horizontal dimensions, x and y . Boundary conditions are specified along the shoreline boundaries, across the mouth of the estuary, and along other open boundaries. Since the motion in the estuary is assumed to be periodic, the dependent variables (water surface height and depth-averaged velocities) are Fourier decomposed. Consequently, the time-dependent equations of motion are replaced by an equivalent set of modal equations, with only x and y as dependent variables. To circumvent the coupling between modes arising from the Fourier decomposition of the non-linear terms, the latter are treated by an iterative procedure. Next, the boundary value problem consisting of the modal equations and appropriate boundary conditions is rephrased in terms of an equivalent variational principle. The variational principle is then used together with a finite element method to solve for the unknown variables, i.e., the coefficients of the Fourier series representations of the free surface elevation and the depth-averaged velocities throughout the estuary. The actual space- and time-dependent currents and heights can then be reconstructed by Fourier synthesis.

A simplified version of the procedure, similar to that reported by Jamart and Winter (1978), is used to compute the barotropic tides in Knight Inlet and the results are compared with available field data. Knight Inlet is a rather strongly stratified fjord and it appears that a significant portion of the barotropic tidal energy is extracted through certain internal mechanisms associated with the flow over the sills (Freeland and Farmer, 1979). Notwithstanding this fact, the model results agree fairly well with measured tidal flow patterns. In particular, it is shown that the observed phase difference can be obtained with a simple "frictional" term, regardless of the nature of the actual dissipation process. (Winter [Jamart])

Pollutant Transport and Sediment Dispersal in the Washington-Oregon Coastal Zone

Research on the transport of dissolved and suspended matter such as pollutants, nutrients, planktonic organisms, and sediment in the Washington

coastal region is being continued. The ultimate goal of the program is to provide tested predictive models to characterize the current velocity field and the associated movement of matter in coastal regions of the Pacific Northwest. Efforts are focused on the following areas:

- 1) Implementation of an interdisciplinary study of the effect of a broad canyon on coastal circulation and on shelf-slope exchange processes.
- 2) Analysis of data from a similar experiment performed in the vicinity of a relatively narrow canyon.
- 3) Analysis of data collected to investigate the existence of a coastal jet on the Washington shelf during winter and spring.
- 4) Application of our bottom Ekman layer model to transient bottom mixed layers such as occur during storms.
- 5) Development of a more general theory for the interaction between wind waves and tidal currents.
- 6) Completion of theories for bedload and suspended load transport of sediment.
- 7) Further examination of the effect of bed forms such as dunes and ripples on the sediment transport theories. (Hickey, J.D. Smith, Clarke, Beck, Geier, MacIntosh, Lee, Paul, Ripley [Bock, Long])

Mid-Ocean Acoustic Transmission Experiment (MATE)

The objective of MATE is to develop an understanding of the effects of the temporal and spatial fluctuations of the oceanic index of refraction on acoustic transmission -- in particular, to understand the physical mechanisms involved in the formation of multiple acoustic paths. The experiment incorporates a balanced program of oceanographic and acoustic measurements and theoretical investigations.

The past year has been dedicated to analysis of the data generated during the field experiment which was conducted during June and July 1977. An enhanced inverse filtering technique has been developed for determining the arrival times of pulses within the received acoustic signal. The main advantage of this new technique is that it is not prone to arrival-time ambiguities that are often present in the more commonly used techniques. As this method is further developed, it will be used to augment the maximum-likelihood multiple-path separation technique developed earlier in this project. The moored temperature measurements, conductivity-temperature-depth (CTD) profiles, and data collected during level runs with the Self-Propelled Underwater Research Vehicle have been analyzed and compared with internal wave theory. A modified internal wave model has been constructed with the use of these data. A new experiment is being designed to directly measure the effects of finestructure. A few modifications to the MATE electronics will be made before the experiment is conducted in FY 80. (Ewart [Reynolds])

APPLIED OCEANOGRAPHY

Review and Analysis of Research Vessel Clearance

U.S. academic and governmental laboratories desiring to conduct certain types of marine scientific research on the continental shelves of other countries have been required since 1964 to obtain permission from these countries. The necessity for seeking permission, however, is being extended to include greater areas and additional kinds of research. Arrangements for clearance have been made through private and governmental channels. At present, the State Department is responsible for processing most clearance requests. However, action by foreign governments sometimes is unduly delayed, and the eventual decision may be unclear. To plan cruises, operators require knowledge of previous experience, but no comprehensive, central file exists, and no analysis of the situation has been made in recent years.

Therefore, it is proposed to review, summarize, and evaluate information on clearance events since the beginning of 1972. Information will be obtained from academic and government sources. An analysis will be made both of the impact of the restrictions resulting from extended foreign jurisdiction on U.S. marine scientific research and of the implications of the accumulated experience for the future conduct of marine scientific research off foreign shores.

At present we are accumulating and evaluating information from the institutions in the academic oceanographic fleet. Failures or near failures to obtain clearances are being assessed in light of future ocean policy. Present problems with clearances are being assessed in order to develop guidelines for better procedures. (Wooster, Healy)

Puget Sound: Oceanography of the Inshore Waters of Washington

Puget Sound has been subjected to considerable oceanographic study, but no attempt has been made to summarize and synthesize the results to give an understanding of the Sound as a system. The importance of proper planning for the future utilization of the Sound has been recognized, and good planning requires such a synthesis. Thus more than 40 oceanographers, including 25 from the Department of Oceanography, are collaborating on a book to be entitled *Puget Sound: Oceanography of the Inshore Waters of Washington*. It will be published by the University of Washington Press. All aspects of oceanography are being summarized and synthesized; overview chapters will integrate current knowledge to provide a picture of the Sound as a system. The treatise, with its comprehensive bibliographies, will serve as a basic document for scientific studies of the future and provide background information fundamental to demographic regional planning. (Coachman, coordinator; Richards, Henry, editors)

Marine Sediment Library

The recently developed curatorial program cooperates with other oceanographic institutions in a national program for the exchange of marine geological data through the National Geophysical and Solar-Terrestrial Data Center at Boulder, Colorado. A Sample Data Information System has been implemented on the Department of Oceanography PRIME Computer so that data from the sample collection is readily available.

The collection contains approximately 9,700 marine geological samples. Most of the samples are from the inland waters and the continental shelf of Washington, the North Pacific Ocean, and Arctic seas. In addition, the collection includes samples from the South Pacific Ocean, Norwegian, Caribbean, Black, and Tasman seas. (Creager, Roberts)

Geological Investigation of the Sedimentary Environment near the Mouth of the Columbia River

This investigation was designed to determine the fate of dredged materials after disposal at U.S. Army Corps of Engineers designated sites in the vicinity of the river mouth, specifically when, where, and at what rate sediment moves from the outer tidal delta, sites A and E, and from Site D at the mouth of the Columbia River.

Completion of the first two years of the program has shown that it is possible to recognize disposal sites used by the Corps of Engineers over some decades, both bathymetrically and through the use of textural and mineralogical properties of the disposed sediment. The natural sediment in the disposal sites has a mean diameter of 150 to 175 μm , making the two populations readily distinguishable. Strong contrasts in mineralogy between the ambient sediment and the dredged material allow recognition of the dispersal pathways of the dredge spoils.

During the past year (third), the field program was confined to monitoring the temporal and spatial changes in the dredged sediment deposited at Site E (off the north jetty) and at Site G (1975 experimental one-time disposal south of the south jetty).

The results are as follows:

- 1) The size distribution of sediments in the estuary and on the outer tidal delta was determined.
- 2) Dredge materials placed at Site G and at other sites on the outer tidal delta are stable, showing little or no change with time.
- 3) Dredge materials placed at Site E just west of the north jetty are eroded during winter storms. Three pathways of transport for this material are identified.
- 4) The highest bottom current velocities at the in-river disposal site (Site D) occur during flood tides with flow generally to the north and east. This suggests that sediment movement in the north channel is in-estuary with a component of movement toward Baker Bay.
- 5) Bottom current speed and direction at the river mouth are closely related to the stage of the tide. (Creager [Borgeld, Walter, Roy])

Submarine Acoustic Anomalies in Norton Basin, Northern Bering Sea

Approximately 3000 km of multi-channel and single-channel seismic reflection records were obtained in August 1978 from the Norton Sound-Chirikov Basin area. These data were collected as part of the first U.S.G.S. resource assessment cruise in the Norton Basin. Areas of the sea floor exhibiting anomalous acoustic responses were more widespread than previously suspected. The CDP data show conclusively that these zones are characterized by low compressional

velocities; the most obvious explanation is the presence of bubble-phase gas in the near surface sediments. The data are being analyzed in an attempt to determine the type and source of gases involved, and the horizontal and vertical extent of these acoustically anomalous zones. (Holmes, McCulloh, Cline)

Multi-channel Seismic Reflection and Sonobuoy Refraction Data in the Outer Southern California Borderland

During April-May 1978, 72 sonobuoy refraction profiles and over 2,000 km of multi-channel (CDP) reflection records were recorded from the Southern California Borderland. The data were obtained as part of the U.S.G.S. Resource Assessment Program, and also to evaluate possible IPOD-DSDP drill sites along the California continental margin. Based on a preliminary analysis of the data, four drill sites were selected and ultimately were approved for drilling by the IPOD-DSDP site safety panel. Three holes were drilled in November 1978. The drill data and geophysical records are being used to interpret the geological history of this complex area. (Holmes, McCulloh)

Ecological Baselines and Monitoring in Port Gardner, Washington

A study has been underway in Port Gardner, Washington, since 1973. The work is an effort to obtain biological and environmental baselines before large pollution control changes in two sulfite pulp mills discharging into Puget Sound. The baseline observations include dissolved oxygen, sulfite waste liquor, nutrient ions, and chlorophyll *a*. Sampling with nets is done for zooplankton, fishes, shrimps, and crabs. Monitoring is conducted to document major changes that might be related to changes in mill operations.

The reduction of mill wastes has been documented from industry records and from samples in Port Gardner. Changes in catch per unit effort of the commercial English sole fishery have been documented. Baseline sampling is continuing. (English, Kisker, Roetscisoender)

Processes and Resources of the Bering Sea Shelf

PROBES is a multidisciplinary and multi-institutional ecosystem study of the Bering Sea focused on the abundant secondary and higher level fauna of outer Bristol Bay. PROBES physical oceanography studies are complemented by the B-BOP study (p. 55).

Physical oceanography studies: During Phase I of the PROBES program, findings in outer Bristol Bay include: (1) There is no major current; (2) the area is a major transition zone between shelf and oceanic source waters, demarked by two fronts. Cross-shelf property fluxes are affected primarily by a "lateral diffusion" defined to include tidal scales; and (3) in and between the fronts there is an extremely rich finestructure -- a manifestation of multiple-layering of the source waters. Cross-shelf property fluxes are physically related to the finestructure.

During Phase II, a model of cross-shelf property fluxes has been applied to five sets of data from the transition zone. Horizontal and vertical eddy coefficients were determined and are now being utilized in a computer model as the basis for the nutrient fluxes, which in turn will be coupled to models of other stages of mass and energy fluxes in the ecosystem.

Future PROBES research will include: (1) experimental work on the fine-structure using a profiling current meter; (2) study of climatic conditioning of the temperature of shelf water, which can be markedly different in different years; and (3) studies of the wind effect on the immediate surface layer, and its effect on the near-surface phyto- and zooplankton residing there. (Coachman, Tripp, Darnall)

Acoustic assessments: Previously, a quantitative acoustic method of assessing the zooplanktonic and sound-scattering organisms was evaluated in Puget Sound. A comparison between net and acoustic methods of assessing standing stock demonstrated that the acoustic method provided speed and detail.

The PROBES data collected during the 1978 field work aboard the R/V *Thompson* provided the first real test of a quantitative acoustic data acquisition system designed to census fishes, micronekton, and macroplankton continuously in the upper 200 m of the water column. Results in the field indicate that the equipment will probably become an extremely useful tool in describing the "real-time" distributions of organisms which heretofore have usually found their way into reports months or years after cruises have been completed. These quantitative estimates are statistically comparable to those obtained by net-haul methods when the target organism's acoustic characteristics are defined. In addition to the direct acquisition of data, the system can be used to detect variations in the distributions of organisms that are of assistance when there is discrete depth sampling by nets. The promise of results of this kind is the ability to plot fields of various particle sizes (copepods, euphausiids, small fishes, large fishes) for comparison with other information now routinely analyzed in real-time on multidisciplinary cruises. This means that fewer, carefully selected net tows will probably suffice for identifying target species or associations, reducing some of the need for the very labor intensive "sorting centers" which presently process the mountains of material collected at sea. (Macaulay, English [Walline])

Outer Continental Shelf Environmental Assessment Program

The OCSEAP program is sponsored by NOAA; the objectives are to (1) provide comprehensive environmental and biological data and information on the Alaska outer continental shelf lease area; (2) define the probable ecological impact of oil exploration, production, storage, and shipment on the outer continental shelf; (3) refine the understanding of key ecological dynamic processes; and (4) provide a basis for *a priori* predictive or diagnostic models of the ecosystem response to loading by petroleum and petroleum by-products.

Norton Sound/Chukchi Sea oceanographic processes: Studies of the Bering Strait region, Norton Sound, and the Chukchi Sea are continuing. The principal objectives are to (1) describe and understand the fluctuations in northward flow; (2) describe the major flow bifurcation west of Pt. Hope; (3) define the temporal and spatial scales important in a dynamical description of the system; (4) determine the circulation in the relatively shallow Norton and Kotzebue sounds; and (5) determine the relationship between the northeastern (N-COP) and southeastern (B-BOP) Bering Sea oceanographic regimes.

The general hydrography and circulation of Norton Sound, based on three CTD surveys and current meter records for various periods of time, has been described in a Technical Report. Circulation in the outer (western) part

of the sound responds closely to the regional transport through Bering Strait; when transport is north (usual condition) circulation in the outer sound is cyclonic, and under conditions of south transport water is backed up in the sound. The eastern sound is isolated, and the water beneath the seasonally warmed surface layer is artifact from the previous winter.

Eleven current meters moored from September 1976 through early summer 1977 were recovered from locations south, in, and north of Bering Strait. The records are now being analyzed, with the objective of determining a dynamical explanation for the transport between the Pacific and Arctic oceans.

Five current meters are presently moored between Norton Sound and Bristol Bay, to be recovered in summer 1979. These records should aid in determining coherence in oceanographic phenomena over the extensive eastern Bering Sea shelf. (Coachman, Aagaard, Tripp, Darnall; R.D. Muench, Pacific Marine Environmental Laboratory)

Bristol Bay oceanographic processes: Through analyses of the extensive current meter, pressure gauge, and CTD data already collected under this program (B-BOP), we hope to improve our understanding of the hydrography, circulation, and dominant mechanisms driving the shelf sea regime of the southeastern Bering Sea. Specific attention will be directed to meteorological forcing of shelf flows, formation and mixing of large scale density inversions found in the interaction zone between the two major water masses, and formation and significance of the front that separates coastal waters from the bulk shelf water.

A major front separating coastal from shelf water, which closely follows the 50 m depth contour, has been described around the perimeter of Bristol Bay. The dynamical explanation is found in the balance of tidal and wind mixing energies as functions of water depth. The significance of the front is an inhibition of cross-frontal fluxes of water properties, thus to a degree trapping materials introduced along the shore to a narrow coastal band. More detailed studies of this front are in progress.

The transition zone of outer Bristol Bay throughout which the shelf water interacts with oceanic water offshore has been described. The zone is bracketed by two fronts, which inhibit cross-shelf fluxes of properties, but between fluxes are significantly enhanced both laterally and vertically by the presence of much finestructure in the water column. Water motions over the whole bay have been found to be dominated by tidal currents, and the long-term (net) flows are extremely small. The data are being further analyzed to determine the nature and magnitude of the effects of storms on advection and mixing of the shelf water. (Coachman, Tripp, Darnall; J.D. Schumacher, Pacific Marine Environmental Laboratory)

Gulf of Alaska mesoscale oceanographic processes: In a study of the circulation on the northern Gulf of Alaska continental shelf from Icy Bay west to Unimak Pass, the following aspects are being stressed: (1) long-shelf variations in mean currents and dependence upon shelf break circulation; (2) cross-shelf variations in mean currents; (3) coherence of long- and cross-shelf current fluctuations over time scales from diurnal to several weeks and over length scales from 10 to 10^3 km; (4) dynamics of the Alaskan Stream, with emphasis on seasonal variability and stream structure in the region of intensification off Kodiak Island; (5) dynamics of tides, in particular, wave

propagation along the shelf and smaller scale effects in restricted regions such as lower Cook Inlet; and (6) interaction of shelf current with bottom topography.

Moored current meter, CTD, Lagrangian drifter (both satellite-tracked drogues and drift cards), and meteorological data are being analyzed by application of physical theory. Analytical techniques include rotary and linear (u,v) spectra, empirical orthogonal functions, and water mass analyses. Emphasis is on dynamical interpretation of the field data. Some of the field work and analyses of data have not been completed.

Specific results, some of which are preliminary, include: (1) definition of long- and cross-shelf flow structures off Icy Bay, including spatial current coherences and wind-current coherence; (2) definition of mean flow patterns in lower Cook Inlet and through Shelikof Strait, including derivation of longshore slope caused by the Alaskan Stream as driving mechanism; (3) field and theoretical analyses of partitioning of energy into baroclinic and barotropic modes in the Gulf of Alaska Subarctic Gyre; (4) definition of seasonal and shorter period current fluctuations from a 3-year current record off Icy Bay; and (5) identification of 2 and 6-7 day period current signals coherent for several hundred kilometers longshore off Kodiak Island. (Mofjeld [Shay]; R.D. Muench, J.P. Blaha, J.D. Schumacher, R. Reed, G. Lagerloef, Pacific Marine Environmental Laboratory)

Transport of sorbed petroleum hydrocarbons in Cook Inlet, Alaska, and the Duwamish River, Washington: Because of the high concentrations of suspended sediments in Cook Inlet, the transport of petroleum-like hydrocarbons by this mechanism may be significant. To test this hypothesis, relatively large concentrations of suspended matter are being recovered and extracted for hydrocarbons. The presence of crude oil is being documented on the basis of n-alkane and aromatic compound patterns as well as C^{13} isotopic compositions. Concurrently, suspended material from the Duwamish River is being analyzed.

Only a few samples have been analyzed to date. In both environment planktonic hydrocarbons and terrestrial plant waxes are dominant in the n-alkane fraction. Isotopic analyses have not been completed. (Cline, Feely [Hamilton])

Laboratory experiments are currently underway to quantify the behavior of crude oil toward suspended detrital particles collected in Cook Inlet. Variables being investigated include temperature, salinity, particle chemistry and morphology, DOC, and the composition of the oil, particularly the concentrations of surfactants.

Preliminary data show that up to 10% of the particle weight is accommodated oil. There appears to be no fractionation of the n-alkane fraction, other than the normal loss of volatiles. The results have been modeled; the model conforms to a model similar to the Langmuir isotherm, although the process is not monomolecular. (Cline, Feely)

Anthropogenic and natural low molecular weight petroleum hydrocarbons in Cook Inlet and Norton Sound: Previous surveys have shown that the waters of upper Cook Inlet can be characterized by unusual concentrations of LMW alkanes and aromatics. Field studies this year will focus on the application of g.c.-m.s. spectroscopy to real-time measurements of LMW aromatic hydrocarbons,

including benzene and C₁ and C₂ substituted benzenes. The source of these hydrocarbons also will be investigated. Work is continuing on the biological input of LMW aliphatics in Kachemak Bay, a eutrophic embayment in lower Cook Inlet.

An anomalous gas seep has been discovered in Trading Bay, the location of the MacArthur oil field. The assemblage of hydrocarbons is largely alkanes, with trace amounts of unsaturates. In Kachemak Bay, the reverse is true, reflecting the importance of biological activity in generating LMW olefins. (Cline [Katz])

Lower Cook Inlet meroplankton: Knowledge of the quantitative temporal and spatial changes in composition and feeding habits of dominate marine organisms in the Kamishak Bay area of Lower Cook Inlet is necessary to evaluate the sensitivity of areas that may be impacted by petroleum development. Specific objectives of this project are to (1) describe the temporal dynamics of the early life history stages of important fishes, shrimps, and crabs at specific sites; (2) evaluate the timing and use of specific areas by critical life stages of fishes.

Biological surveys which have provided species lists and general information on the relative abundance and distribution of important marine organisms were analyzed as an aid in planning the field program.

Distributions of abundance of early life history stages of fishes, shrimps, and crabs have been plotted for four seasons within one year. Collections have been made from spring and summer of an additional year. (English, Kisker, Roetcisoender, Daly, Legacie)

Deep Ocean Mining Environmental Study

The objective of DOMES is to identify potential environmental impact problems to be expected from commercial-scale mining of deep ocean manganese nodules. Baseline studies (Phase I) on existing environmental conditions required by the biological, chemical, physical, and geological investigations have been completed. Phase II studies are concerned with prototype mining tests.

Commercial-scale mining of manganese nodules in the tropical North Pacific is scheduled to begin in the 1980's. The mining systems will gather nodules from the sea floor by a towed collection device and transport the nodules through a pipe to a surface mining vessel. In addition to nodules, bottom water, sediments, and benthic biota will also be transported in the pipe and these will be discharged into the surface water after separation of the nodules. The collector on the ocean floor is expected to scour the top layer of sediment and will discard most of these sediments within tens of meters of the ocean floor, thereby creating a benthic plume.

Phase I studies on the pre-mining conditions in the commercial nodule mining area have been summarized and those effects that are potentially directly discernible have been identified (NOAA Technical Memorandum ERL MESA-33). The field studies involved measurements of currents, light penetration, suspended particulate matter, pigments, primary productivity biochemical parameters, and zooplankton and micronekton in the upper layer. Temperature,

salinity, nutrients, and dissolved oxygen content were measured throughout the water column. The studies in the lower water column included currents, suspended particulate matter, and macrozooplankton measurements. On the sea floor, the benthic population and characteristics of the sediments, and pore water were determined.

Based on mining vessel discharge and sediment characteristics, predictions of the dispersion of fine particulates, both in the surface layer and in the benthic boundary layer, were used to estimate the extent of the mining effects. Measurements of light intensity and suspended sediment concentrations in the mixed layer were used with modeled sediment distributions to estimate reduced light intensities. Decreases in primary productivity resulting from light reduction were then estimated. Effects of suspended particulates on biological activity aside from light reduction were also examined.

On the basis of estimated characteristics of the mining discharge, it is predicted that there will be no detectible changes in the temperature, salinity, density, dissolved gas, and dissolved trace metal content of the waters in the mixed layer caused by introduction of mining discharge. Surface-suspended sediment is predicted to be measurable to a distance of 50-100 km from the mining vessel. It is estimated that light reduction, caused by an increase in the suspended particulate matter introduced by the mining discharge, will result in a reduction in primary production close to the mining vessel. Calculations show that enhancement in primary productivity, due to addition of nutrients with bottom water in the mining discharge, is negligible. The benthic plume will be measurable to tens of kilometers from the collector device.

Our estimates prior to actual mining operations indicate that there will be no directly discernible large-scale effect beyond 100 km of the mining vessel in the upper water layers from deep ocean mining of manganese nodules. The benthic fauna intercepted by the collector will be destroyed; however, the area affected is small relative to the potential mining area. A larger benthic area will be affected by the deposition of the resuspended clays and silts.

Phase II studies include the monitoring of two mining tests, April-May 1978 and November 1978. These investigations are designed to address several objectives associated with short-term near-field effects:

- 1) identify and characterize the discharges into the marine environment that originate from the mining system;
- 2) characterize the manner in which the mining system interacts with the seafloor;
- 3) characterize the temporal and spatial dispersion of materials from the discharges of the mining systems;
- 4) identify and characterize aspects of the marine ecosystem most susceptible to impact by the mining systems;
- 5) characterize the immediate environmental impacts imposed by the mining system.

In addition, basic information on the mining discharges can be used in assessing the potential long-term impact of the mining activity. (Ozturgut, G.C. Anderson, Burns; J.W. Lavelle, S.A. Swift, Pacific Marine Environmental Laboratory)

Nutrient programs: As a result of data collected during Phase I, a paper on the "Water column nutrient chemistry in the tropical North Pacific DOMES sites A, B, and C" has been published. (J.J. Anderson)

Results from Phase II include: Nutrient ion analysis of water from the mining plume between 0.5 km and 1.0 km from the mining ship showed that the high nutrient ion concentrations of the discharge water are essentially diluted beyond recognition. This result is important as it was generally thought that mining activity would result in a significant zone of upwelling. The zone of high nutrient ion concentrations exists in the immediate vicinity of the mining ship and does not persist for more than an hour.

Laboratory studies determined that bacterial growth was stimulated in surface seawater to which mining fines had been added.

Samples for particulate ATP from the mining plume indicated that the bacteria, associated with the mining fines, which remained in the mixed layer increased in biomass for at least a day following discharge. A net increase of viable carbon of approximately $3 \text{ mg C/m}^3/\text{day}$ could be attributed to this heterotrophic source. This compares with a phototrophic rate of $2 \text{ mg C/m}^3/\text{day}$ in the same area. (R.J. Ozretich, R.A. Ozretich, Wisegarver)

Suspended particulate matter program: This program was initiated to monitor the three-dimensional dispersal of particulate debris introduced into the surface and bottom waters of the eastern tropical Pacific Ocean by manganese nodule mining activities. Specifically, an attempt will be made to answer the following questions: (1) What is the vertical and horizontal rate of the debris plume dispersal? (2) What is the concentration and composition of material in the plume? (3) How long does the plume remain in the surface mixed layer? (4) Does the plume material accumulate at the pycnocline? (5) How is the plume material removed from the ambient water?

Preliminary analysis of data from the first monitoring cruise -- spring 1978 -- has been completed. The following papers on the results of this research have been published or are in press: Baker, E.T. and Feely, R.A. (1978) Chemistry of oceanic particulate matter and sediments: duplications for bottom sediment resuspension. *Science* 200: 533-534. Baker, E.T. and Nevins, J.B. (1978) The distribution and composition of suspended particulate matter above the manganese nodule province of the eastern equatorial Pacific Ocean. *Proc. Offshore Tech. Conf., OTD-3139*: 252-258. Baker, E.T., Feely, R.A., and Takahashi, K. (in press) Chemical composition, size distribution, and particle morphology of suspended matter at DOMES sites A, B, and C: relationships with local sediment composition. In Bischoff, J.L. and D.Z. Piper (eds.), *Marine Geology and Oceanography of the Central Pacific Manganese Nodule Province*. (E.T. Baker)

Impact of a prototype manganese nodule mining test on the benthic community: The impact of pilot-scale manganese nodule mining on the deep-sea benthic community is being investigated. Sediment samples were collected, using 0.25 m^2 box cores, just prior to, and soon after, a prototype mining test in the equatorial Pacific. All macrofauna are being sorted from the sediments, and the polychaetes and isopods (which together comprise over half the fauna) are being identified to species. The degree and pattern of the impact will be determined by various community analyses and by spatial autocorrelative techniques. (Jumars [Eckman]; K. Fauchald, U.S. National Museum and G.D. Wilson, Scripps Institution of Oceanography)

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- Bruce A. Taft, Ph.D., California, San Diego. Research Associate Professor. Physical oceanography, ocean circulation.
- Richard L. Temkin, Ph.D., New York, Buffalo. Research Associate. Physical oceanography, climate modeling.

- Richard B. Wearn, Jr., Ph.D., Harvard. Research Associate. Physical oceanography, mid-ocean dynamics, ocean pressure fluctuations.
- Pierre L. R. Welander, Ph.D., Stockholm. Professor. Theory of general ocean circulation, large-scale atmosphere-ocean interaction.
- John T. Whetten, Ph.D., Princeton. Adjunct Professor. Geological oceanography, sedimentology, sedimentary petrology.
- Donald F. Winter, Ph.D., Harvard. Professor. Applied mathematics, hydrodynamics, biological modeling.
- Warren S. Wooster, Ph.D., California, San Diego. Adjunct Professor. Physical oceanography, ocean circulation, fishery oceanography and ocean affairs.

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- | | |
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| Robert Barrick | Dorothy Lowman |
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| Rex Johnson | Jeanne Summerhays |
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| Dale Kisker | Richard B. Tripp |
| Kathy Kroglund | Marc Weinstein |
| Mary C. Larsen | David Wisegarver |
| Joyce Lehner | Karen Zakar |

DOCTOR OF PHILOSOPHY DEGREES AWARDED IN 1977-78 WITH TITLES OF DISSERTATIONS

James J. Anderson, "Identification of tracing of water masses with an application near the Galapagos Island."

Richard Blank, "Correlation of Cenozoic deep sea sediments of the equatorial Pacific Ocean."

Augustine Tat Hang Chan, "A comparative physiological study of marine diatoms and dinoflagellates in relation to irradiance and cell size."

Robert Jarman Feller, "Life history and production of meiobenthic harpacticoid copepods in Puget Sound."

Paul C. Henshaw, Jr., "A study of the geochemistry of pelagic sediments: the interaction of trace metals and magnetic minerals with sedimentary environments."

Murray C. Levine, "Statistical description of internal waves and temperature fine structure in the deep ocean."

Johann Lutjeharms, "Meso-scale dynamics in the southern ocean: a statistical analysis of historical data."

Michael C. Macaulay, "Quantitative acoustic assessment of zooplankton standing stock."

Charles A. Nittrouer, "Detrital sediment accumulation in a continental shelf environment: an examination of the Washington shelf."

Frank R. Shuman, "The fate of phytoplankton chlorophyll in the euphotic zone - Washington coastal waters."

William M. Smethie, "An investigation of vertical mixing rates in fjords using naturally occurring radon-222 salinity as tracers."

Julio Vidal, "Effects of phytoplankton concentration, temperature, and body size on rates of physiological processes and production efficiency of the marine planktonic copepods, *Calanus pacificus* Brodsky and *Pseudocalanus* s.s."

MASTER OF SCIENCE DEGREES AWARDED IN 1977-78

Laurie S. Balistrieri
Timothy S. Bates
Barbara Jane Bauer
Charles D. Boatman
Jeffrey Borgeld
Norman F. Breitner
Andrea A. Copping
James E. Eckman
David W. Harker
Wilson Hom
Jeffrey E. Hughes
Richard A. Jahnke
Terry L. Keefer
Kenneth King
Pamela A. Kingsbury
William M. Landing

James H. McKenzie
Terren M. Niedrauer
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Elizabeth A. Quinlan
Andrew A. Ruotsala
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Jeffrey J. Sawlan
Joseph L. Scott
Robert F. L. Self
Satish R. Shetye
Nungjame C. Shi
Gary L. Tachon
Kozo Takahashi
Daniel E. Wartenberg
Jeanette Duen Ying Yen

BACHELOR'S DEGREES AWARDED IN 1977-78

John L. Bowles	Victoria Kromer
Marilyn Rai Buchholtz	Joyce M. Lehner
Gillis Yves Bussod	Carolyn Lie
Sally J. Cairns	Terence L. Lingbloom
Glen H. Carpenter, Jr.	Dale C. Mann
Albert H. Chapdelaine, Jr.	Linda S. Matheson
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Ronald M. Graves	Keith E. Phillips
Charles W. Green	Eric H. Raisters
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Andrew H. Hergert	Eddie R. Riley
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CONTRIBUTIONS

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