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*Scripps
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ANNUAL
REPORT
1989

DEDICATION

Internationally acclaimed for innovative work in biochemistry, Andrew A. Benson has a remarkable ability to visualize a wide range of biological processes. He has traveled from the northern slopes of Alaska to the Great Barrier Reef in search of clues to understanding how organisms function.



Benson's curiosity about living systems was fostered by his father, a country doctor. After earning his doctorate in organic chemistry and neurophysiology from the California Institute of Technology in 1942, he joined the faculty at UC Berkeley, where he was an instructor in the chemistry department and assistant director of the Lawrence Radiation Laboratory's Bio-organic Group. There he worked with pioneers in radioactive carbon studies to isolate the first products of carbon dioxide fixation in photosynthesis—compounds involved in absorption of CO_2 by plants and their production of sugar.

While still at UC Berkeley, Benson joined his first Scripps cruise and made the earliest oceanic measurements of carbon-14 plankton uptake (primary production). He later went to Pennsylvania State University, where as a professor of agriculture and biological chemistry he continued radiobiochemical investigations. Benson returned to California to join the faculty at the UC Los Angeles School of Medicine.

In 1962, he joined Scripps as a professor in the Marine Biology Research Division. During his years at Scripps, he served as founding chair of the Marine Biology Department, as associate director of the institution, as division chair, and as director of the Physiological Research Laboratory.

The author of about 250 scientific papers, Benson's diverse research has delved into energy sources in marine organisms, the accelerated aging process in salmon, and the metabolism of arsenic in aquatic plants. A member of the National Academy of Sciences, he has served on numerous advisory panels and has received several honorary degrees and research awards.

An active seagoing scientist, Benson continues a 22-year tradition of leading research cruises to salmon streams. Also this year he joined in an expedition to examine coral and phytoplankton in the Indian Ocean near the Seychelles aboard a Soviet research vessel.

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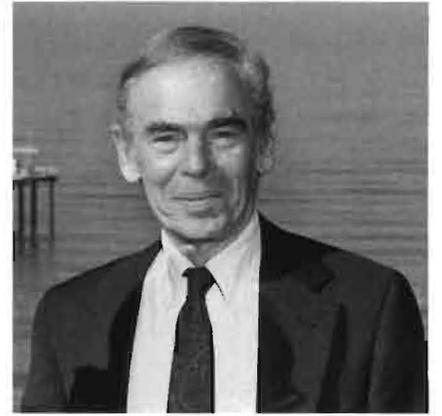
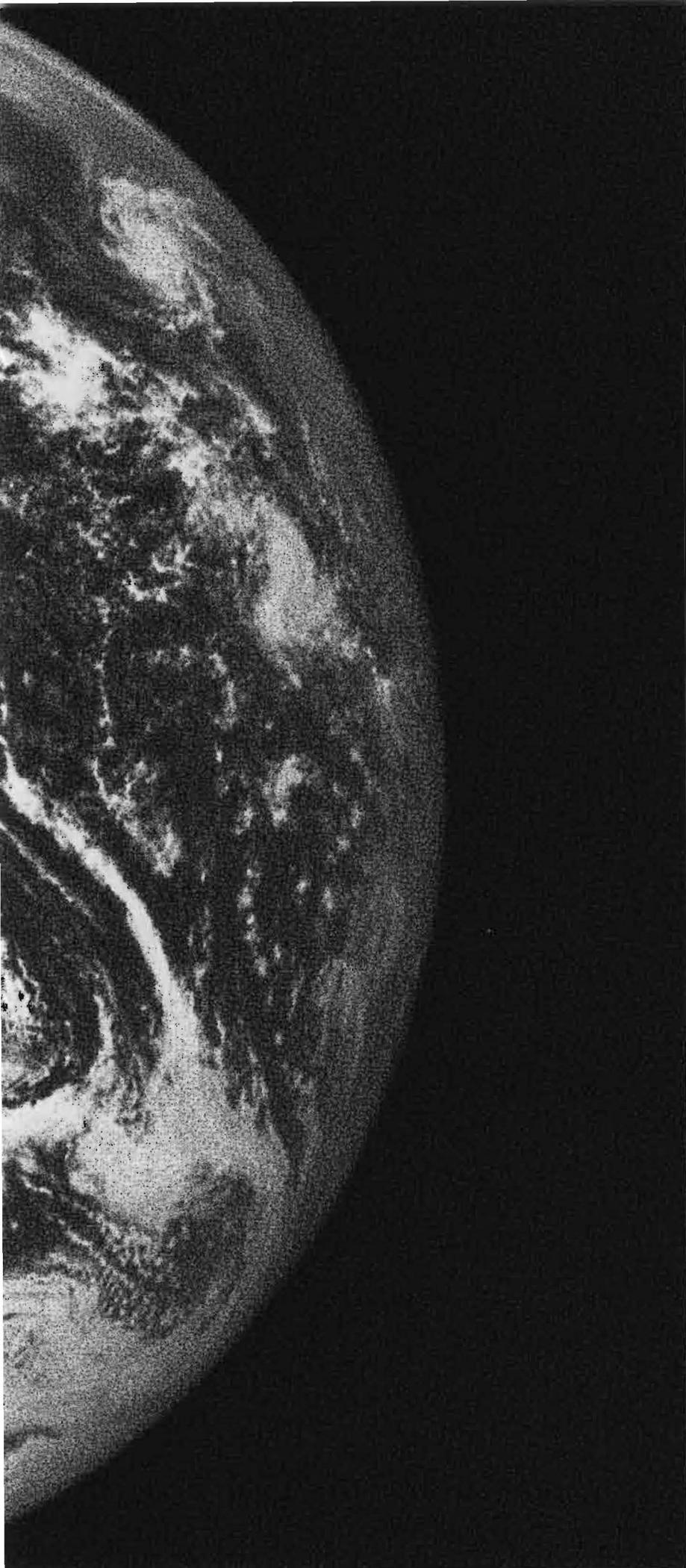


This is the University of California, San Diego, Scripps Institution of Oceanography Annual Report 1989 (for the year ending June 30, 1989). ISSN 1046-9443. A major portion of the work reported herein was supported by the National Science Foundation and the Department of the Navy. For more information on the institution please write: Technical Publications, Scripps Institution of Oceanography, A-033B, La Jolla, California 92093.



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INTRODUCTION

AS THIS DECADE OPENS, global scientific problems are increasingly coming to the fore, creating strong concerns for scientific responsibility, and new opportunities for Scripps to help solve major problems facing our planet. Although the crucial role of the oceans in determining global climate is just now being recognized in the press, we have regarded it as a major part of the Scripps research agenda for years. Our concern for the oceans and the environment as a whole is reflected in the research descriptions that follow. The research choices that are made now will form the foundation of future policy actions.

Our scientists continue to cooperate on multinational programs, many focusing on causes and effects of global change. Involvement in large, international projects is ongoing; however, individual research continues to be the mainstay of the Scripps program.

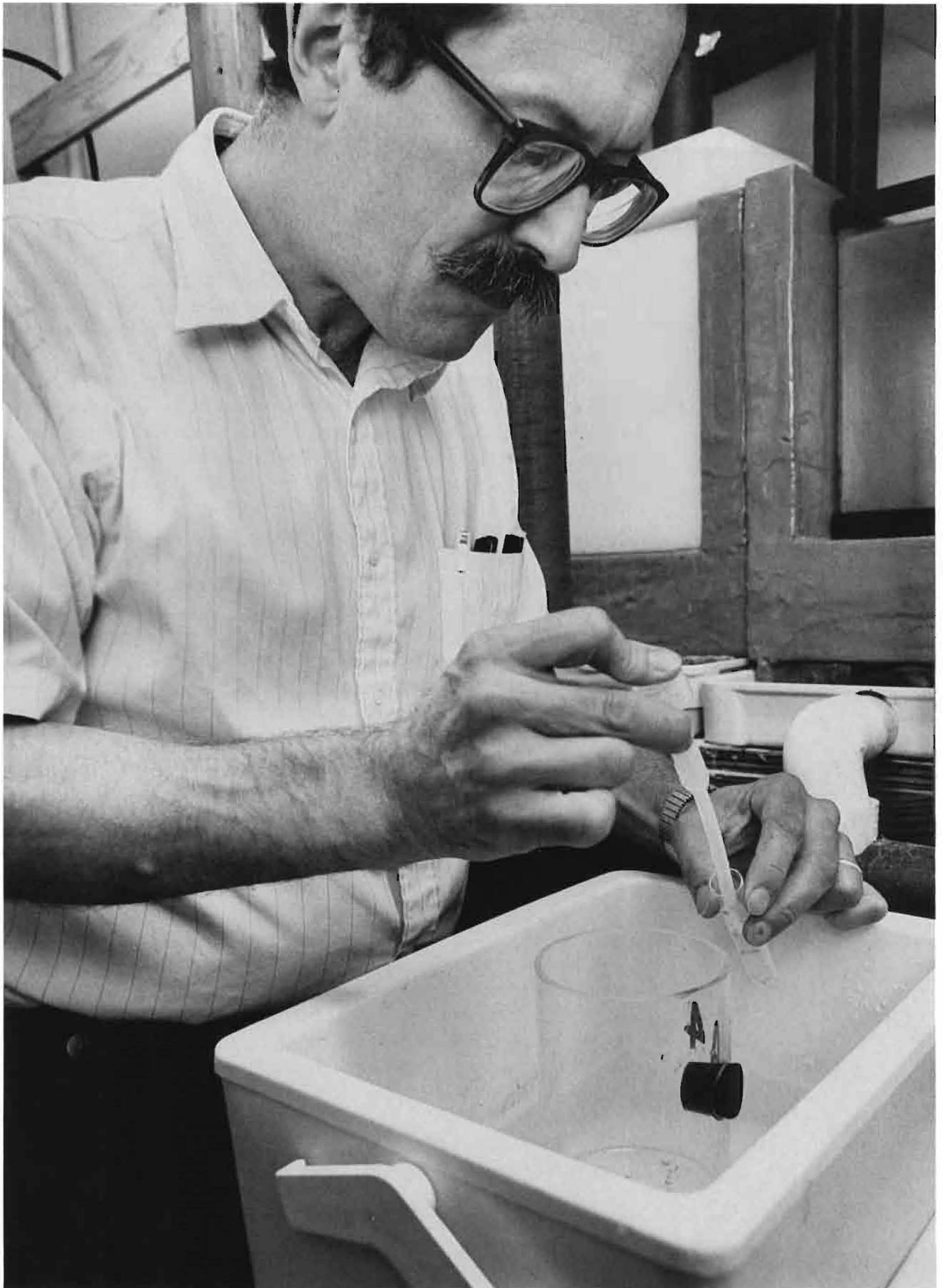
Through recruitment and reorganization the institution is gradually taking a different direction. For example, fifteen percent of our faculty have assumed their positions at Scripps over the past two years. Furthermore, I foresee an increase equal to or perhaps even greater than this over the next several years. This increase addresses prior losses in the areas of geological sciences and geophysics, maintains our strengths in the other curricular areas, and adds new emphasis on molecular marine biology and global change, including atmospheric chemistry and satellite geodesy. This endeavor, coupled with the reorganization discussed below, will prepare Scripps for the 1990s.

A reorganization of the institution reflecting our new directions occurred on July 1, 1989. The Ocean Research Division has been split into two new divisions—the Climate Research Division, headed by Dr. Richard Somerville, and the Physical Oceanography Research Division, chaired by Dr. Robert Knox. The intercampus headquarters of the Institute of Marine Resources remains at Scripps, but those Scripps scientists formerly with IMR are now either with other divisions or are a part of the new Marine Research Division. Dr. William Fenical, acting director of IMR, now chairs the Marine Research Division. As of July 1, 1989, Dr. Sally Ride became the Director of the California Space Institute.

As will be noted in the Honors and Awards section, many awards were earned by our scientists again this year. I make special mention of Dr. Edward Goldberg, co-recipient of the prestigious Tyler Prize for Environmental Achievement.

As we launch this decade, with its new geopolitical structures, we confidently look forward to Scripps fulfilling its responsibilities in this new order.

Edward A. Frieman, Director
March 1990



Dr. A. Aristides Yayanos places amphipods in a small test tube to be transported to a Co-60 gamma ray radiation source.



HIGHLIGHTS

THE DEEP-SEA ORGANISM AS AN ENVIRONMENTAL BAROMETER

by A. Aristides Yayanos

EXCEPT FOR ITS HYDROTHERMAL REGIONS, the deep sea is a stable, cold, dark, and high-pressure environment. Human activities may change this stability and affect the deep ocean in two ways. The food supply for deep-sea organisms is thought to come from the same 1,000 m of upper ocean as man's. Fecal pellets, dead organisms, molts, and pieces of sea-surface organisms sink to the bottom where they nourish deep-sea life. Thus fisheries may alter the nature of the food supply to the deep sea. The second, perhaps more influential human activity, is waste disposal. Understanding how deep-sea organisms respond to stress is imperative as the use of the oceans for waste disposal increases. We cannot assume that deep-sea organisms and shallow-water organisms will show identical levels of sensitivity to stress, as is evident in recent results with deep-sea bacteria.

Deep-sea bacteria are exquisitely sensitive to radiation and to certain chemicals; they rank among the most radiation sensitive organisms known. Deep-sea bacteria are very sensitive to mercuric chloride (a poisonous compound used as a disinfectant, antiseptic, and incorporated into insecticides, preservatives, and other everyday compounds). The bacteria are easily grown under simulated deep-sea conditions in the laboratory, and should prove valuable for toxicity testing.

The study of the physiology, biochemistry, and genetics of deep-sea life is, however, a challenge because the high pressures at depth create difficulties for field and laboratory studies. Man can enter this high-pressure environment only with the protection of an expensive and infrequently available submersible vehicle. In the laboratory, deep-sea organisms can be studied only under the protection afforded them by a pressure vessel. Thus there is a real



Ambipods from 2,000 m deep, where the pressure is 200 atm, survive in atmospheric pressure aquaria.



FILAMENTS IN THE CALIFORNIA CURRENT: THE COASTAL TRANSITION ZONE PROGRAM

by Thomas L. Hayward

physical barrier between the scientist and the experimental deep-sea organism. These field and laboratory approaches complement one another. The former provides information in a natural setting. The latter allows for a large number and variety of tightly controlled experiments.

A little more than 10 years ago, we discovered how to keep and study deep-sea bacteria in laboratory culture. Since then studies have shown several interesting physiological and biochemical features of these bacteria. One of the most striking is that their growth physiology is tuned to the pressure of their environment. The increasing pressure with depth in the ocean forces zonation of species in a way analogous to decreasing temperature on the earth's surface. Another interesting characteristic is their rapid growth in the presence of sufficient nutrients. These bacteria undoubtedly play an important role as decomposers in the deep-sea food web.

Over three hundred bacterial isolates from depths of 2,000 to 10,500 m are now kept at high pressures in a culture collection at Scripps. The availability of these organisms to other scientists should greatly facilitate our understanding of the biology of these organisms.

Another group of deep-sea organisms, amphipods, is also being used to reflect chemical ocean changes. Eleven years ago we began to retrieve live amphipods by using pressure-retaining traps. Amphipods are an excellent subject for study: a major component of the large mobile scavenger community, they have a large internal dose of ionizing radiation from accumulating large amounts of the naturally occurring radionuclide Po-210, and they can be caught

almost everywhere in the deep sea. As in bacteria, there is a correlation between capture depth and pressure sensitivity. For example, amphipods from 10,500 m (1,500 atm) do not tolerate decompression to 340 atm whereas those from 5,800 m (580 atm) can be decompressed to 200 atm and those from 2,000 m (200 atm) to 1 atm. Although animals from the greatest ocean depths are the most interesting, a key to progress is the use of amphipods from a depth of 2,000 m off of the San Diego coast. These can be collected predictably on short cruises and do not require pressure for survival over a period of months. We have begun studies on the radiation sensitivity of deep-sea amphipods and plan to extend these studies to other forms of stress. The hope is that these studies with bacteria and amphipods will help to clarify the effects of the dumping of wastes in the oceans. Such studies may also be useful for explaining how extinctions of marine species have occurred on several occasions in the past.

Suggested Reading:

Yayanos, A. A. Evolutional and ecological implications of the properties of deep-sea barophilic bacteria. *Proceedings of the National Academy of Sciences, U.S.A.*, v.83, 1986. pp.9542-9546.

Yayanos, A. A. and E. F. Delong. Deep-sea bacterial fitness to environmental temperatures and pressures. In *Current Perspectives in High Pressure Biology*, edited by H. W. Jannasch, R. E. Marquis, and A. M. Zimmerman. New York, Academic Press, 1987. pp.17-32.

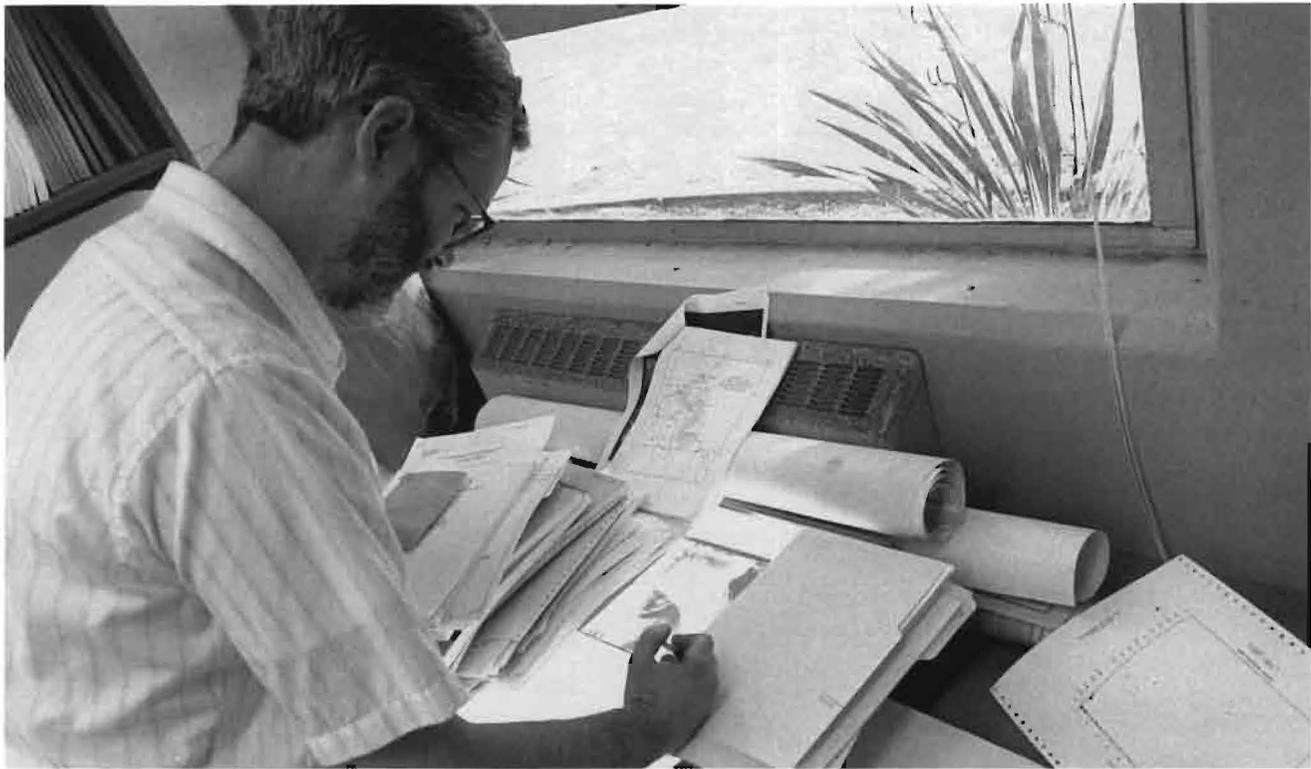
FILAMENTS, NARROW TONGUES OF COLD WATER, have been observed in satellite images of sea-surface temperature of the California Current. Scientists are interested in understanding the structure of these coastal filaments because they represent an important source of physical and biological variability in the coastal region, and because their mechanisms of formation and dissipation are not well understood.

Eastern boundary current systems, such as the California Current, are productive areas important to commercial fisheries. These systems vary widely and their patterns of chemical and biological properties are determined largely by the physical structure. Understanding and, ultimately, predicting change in biological properties will require an understanding of the physical structure of the region and how it is linked to chemical and biological structure.

The filaments (30-50 km wide) appear to originate near the coast and can extend 300 km offshore. Satellite images of ocean color show high chlorophyll, and thus high phytoplankton abundance, in these features. Scientists observed that filaments are common in strong coastal upwelling areas, which lead to an early suggestion that filaments may somehow be caused by the upwelling process. However, upwelled water also provides the cold "dye" that makes the filaments visible to satellites. Scientists don't



Dr. Thomas L. Hayward compares the spatial distributions of chemical and biological properties measured on cruise SQ87.



know if filaments exist without upwelling. Shipboard observations of velocity structure made with a Doppler acoustic current profiler show high offshore velocities in filaments identified with satellite imagery. These initial observations suggested that filaments have an important role in transporting productive coastal water, with its associated biota, to the offshore parts of the California Current. Study of the physical, chemical, and biological structure of coastal filaments is the research focus of the Coastal Transition Zone (CTZ) Program, a multi-institutional initiative sponsored by the United States Office of Naval Research.

During the last three years Scripps researchers conducted field sampling in the coastal region of central and northern California as part of the CTZ Program. Data from a cruise aboard R/V *New Horizon* helped describe the complicated three-dimensional structure near Pt. Arena. With these data scientists are examining the relationship between physical structure and chemistry and biology in the survey region. The patches of cold, saline water found near the coastal promontories at Pt. Arena

and Cape Mendocino were high in nutrients and low in dissolved oxygen. This indicated that a physical process, such as coastal upwelling, had recently transported water from depths below the euphotic zone to the mixed layer. The associated nutrient input had stimulated phytoplankton growth, elevating the chlorophyll concentration.

These rich patches were separated from warm, oligotrophic (low production) offshore water by a narrow, high-velocity coastal jet composed of low-salinity, low-nutrient water, which flowed south along the coast. The coastal jet originated to the north of the sample grid, and its shoreward side marked the boundary between rich coastal water and oligotrophic offshore water. The seaward side of this meandering jet appeared to form the filaments seen in satellite images.

Structure in the survey region was also modified by a cyclonic mesoscale eddy south of Cape Mendocino. This eddy also strongly affected nutrient and chlorophyll distributions. Previous CTD surveys indicated that the eddy is a recurrent feature

that may be caused by an interaction of the coastal jet with the shoreline topography. The nutrient concentration was high in the eddy center. Chlorophyll was elevated in a ring that defined its outer edge, a pattern caused by a combination of the secondary circulation (mixing and entrainment of water by the eddy) and the time lag required for phytoplankton growth.

The cruise data show that physical structures such as filaments, eddies, and jets strongly affect chemical and biological properties in the coastal region. New models that include these complex structures will be necessary to relate physical and biological structure in the coastal region.

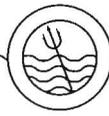
Suggested Reading:

Flament, P. J., L. Armi, and L. Washburn. The evolving nature of an upwelling filament. *Journal of Geophysical Research*, v.90, 1985. pp.11,765–11,778.

The Coastal Transition Zone Group. The Coastal Transition Zone Program. *EOS*, v.69, 1988. p.608.



Dr. Mark D. Obman applies lipids extracted from planktonic copepods to quartz rods coated with silica gel. The lipid mixtures are then separated and quantified by thin-layer chromatography/flame ionization detection.



RESEARCH ACTIVITIES

MARINE LIFE RESEARCH GROUP

Many of the scientific projects being conducted at Scripps are reviewed briefly in these reports. Some departments have elaborated on a few studies, while other groups give a summary of many projects. The majority of these studies are being funded by the National Science Foundation, Office of Naval Research, Department of Commerce, National Aeronautics and Space Administration, and other governmental agencies.

Scientific papers listed in the Publications section will lead the reader to a more in-depth coverage of the topics discussed in the Research Activities section.

GLOBAL CLIMATIC CHANGE, both natural and anthropogenic, is a matter of great concern to all facets of society because almost everything is in some way influenced by climate. World climatic events have dramatic impacts on the oceanic distribution of heat and energy, the strength and path of ocean currents, and the distribution of their associated fauna and flora.

Since its inception, the Marine Life Research Group has been concerned with large-scale changes of the oceans and has conducted pioneering studies in the field of global change. In acknowledgement of the fortieth anniversary of both MLRG and the inter-agency research program of which it is a part, this section presents a brief review of the history and accomplishments of the program over its lifespan.

Early this century, the Scripps Institution of Oceanography, in cooperation with state and federal agencies, began field studies on the sardine population off the California coast. Those studies were stimulated by the economic value of this fishery to California and the desire for prudent management.

In the late 1930s the sardine fishery entered a period of serious decline. The industry and the California Legislature responded with an infusion of new research money, and a plan "to determine what controls variations in population size and availability in oceanic fishes off the west coast of North America." The California Cooperative Oceanic Fisheries Investigations (CalCOFI), a partnership among the Marine Life Research Group of Scripps, the National Marine Fisheries Service, and California Department of Fish and Game, was born. MLRG was charged with the study of the physical-chemical and biological milieu in which fishes live. To all groups involved went the mandate to take ships to sea to collect needed



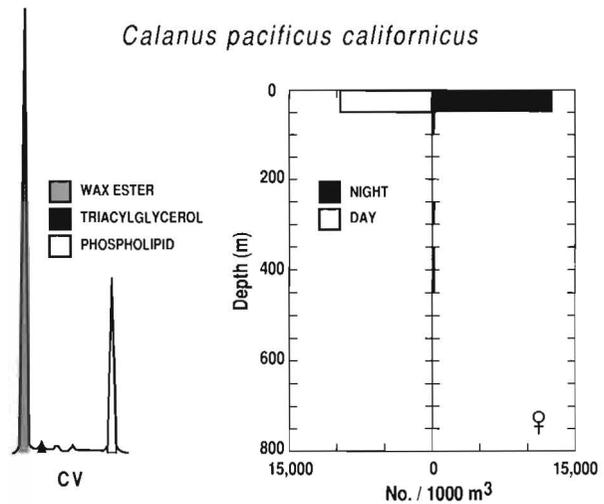
Contrasting diel vertical migration behavior (right panels, adult females) and lipid profiles (left panels, copepodid stage V) of three species of planktonic copepods found commonly in the California Current System.

Copepods for these lipid and vertical migration studies were collected in the California Current as part of Dr. Mark D. Ohman's studies of copepod population dynamics.

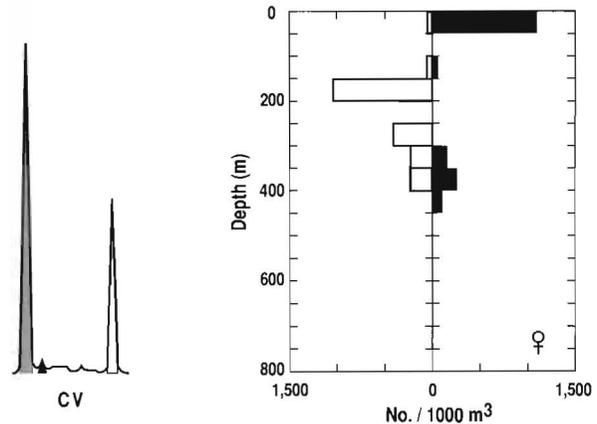
Right panels: Three different migration types are illustrated, reflecting predator avoidance and foraging behaviors that vary among species. At the time of this collection, *Calanus pacificus californicus* was a surface-dwelling nonmigrant, most *Metridia pacifica* migrated vertically into surface waters at night, while *Eucalanus californicus* was a mid-depth nonmigrant.

Left panels: Chromatograms of lipids extracted from the same three species. Wax esters are the primary storage lipid of *Calanus pacificus californicus* and *Metridia pacifica*, but *Eucalanus californicus* stores mainly triacylglycerols. Because triacylglycerols are thought to turn over more rapidly than wax esters, copepods like *E. californicus* that reside continuously in intermediate depths may have different feeding behaviors and metabolic adaptations than copepods that enter the surface layer of the ocean.

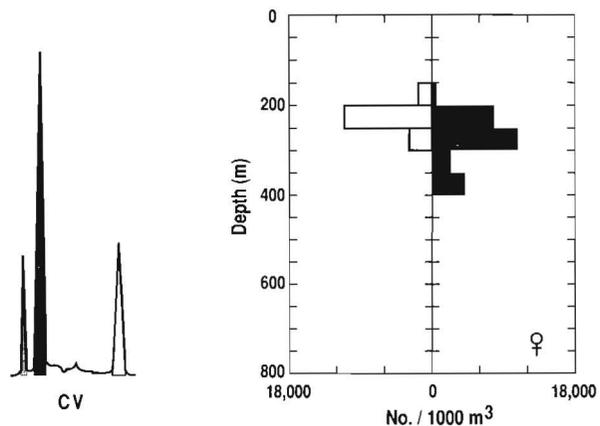
Calanus pacificus californicus



Metridia pacifica



Eucalanus californicus



data. CalCOFI's marriage of fishery biology and the oceanographic disciplines has become known as the oceanographic approach to fishery research. This ecosystem perspective has had wide impact on ocean research programs throughout the world. Now, after 267 expeditions, CalCOFI has assembled the most complete ocean time series in the world, and the data set continues to grow. Although its original purpose was limited to a specific fishery research problem, it now has great value in aiding researchers' understanding of large-scale



events and providing them with a baseline against which to evaluate global change.

Historic episodes, when properly documented, help scientists understand the probable effects of global change. For example, occasionally swarms of red "tuna crabs" drift up on southern California shores and sports fishermen take warm-water, oceanic species, such as mahi mahi, in abundance. These biological anomalies are related to large-scale changes in currents driven by redistributions of heat and wind energy. In 1957-1958 such an episode coincided with several major events: a strong El Niño in the Southern Hemisphere, the first recorded major typhoon in Hawaii, an early ice melt in Alaska, nesting failure and high mortality of seabirds off South America, and a massive decline in the plankton biomass in the California Current.

In response to the 1957-1958 observations, the 1960 CalCOFI symposium brought together biologists, oceanographers, meteorologists, and astrophysicists to discuss these widespread and diverse anomalies. They could clearly see that the unusual observations being made in the far reaches of the Pacific Basin were related. So much was learned at this symposium that new research programs were started in ocean climatology, physics, and biology (including the Climate Research Group and the NORPAX program at Scripps). Ocean climatologists began to confirm that local weather is influenced by large-scale climatic forcing, often of a global extent. In 1975 two Scripps graduate students, a biologist with MLRG and a physical oceanographer, studied the long-term patterns of California Current fluctuations. They worked independently, but both used CalCOFI data, and they found that biological and physical patterns were closely related. For the first time the biomass in the California Current could be statistically linked to the strength of the southward flow, which appeared correlated

to climatic patterns over the North Pacific Basin. There is little doubt that physical changes in the ocean and the overlying atmosphere effect the biology of the sea.

The 1983-1984 El Niño event provided another natural experiment for MLRG researchers. A major drought hit Australia and Indonesia in 1982, presaging the 1983 failure of the Christmas Island seabird reproduction, a massive reduction in plankton, poor anchovy growth off southern California, decreased sea lion recruitment, and poor salmon fishing off Washington and British Columbia. Intensified CalCOFI sampling during 1983 and 1984 provided a close look at the links between ocean physics and biology. Scientists learned that in California waters the El Niño phenomenon is characterized by a slowing and shifting of the core of the southerly flowing California Current. This correlates with a rise in sea level that amplifies the erosive effects of storms. An unusual amount of less-productive water moves toward the coast, resulting in a depression of the thermocline and a dramatic decrease in plant nutrient levels and in biomass, thus reducing the fertility of the ecosystem. Such El Niño episodes serve as models for the impacts of global warming on the California Current ecosystem and other marine environments.

Changes occurring over longer periods are even more important to our understanding of global events. Each expedition in the continuing CalCOFI series enhances the ability of scientists to distinguish and evaluate global climatic change and human impact, while new technologies permit the formulation and testing of hypotheses about the interaction of biological and physical systems. After 40 years MLRG and CalCOFI continue to contribute to the understanding of the complex feedback systems that connect the biosphere to biogeochemical cycles and the global climate system.

MARINE PHYSICAL LABORATORY

THE SCIENTISTS AT the Marine Physical Laboratory (MPL), directed by Dr. Kenneth M. Watson, are developing new instruments and new deep-sea vehicles to transport instruments for their oceanic measurement programs.

Dr. William S. Hodgkiss's group continued investigations of underwater acoustics and signal processing, with emphasis on the Swallow float array program. Group scientists fabricated and operated a freely drifting array to measure ambient ocean noise in the 1-20 Hz frequency range. Each buoy in the system emits a signal that is received by the other buoys. When the locations of all elements are known, the outputs of the array can be used to assess the directionality of the ambient noise field.

Dr. Hodgkiss participated in a very low frequency (VLF) ambient noise experiment conducted off the southern California coast in 3,700-m deep water near the San Juan Seamount. The sensors used in the experiment included: Swallow floats, VLF sonobuoys, and ocean bottom seismographs. Data analysis will provide the temporal and spatial characteristics of ambient noise,



Dr. Victor C. Anderson and Fred H. Uhlman check the saltwater hydraulic hoses for the RUM III manipulator boom.

Opposite page: Ronald C. Horn directs the recovery of RUM III on board R/V New Horizon.

their relationship to weather, sea surface conditions, and shipping traffic in the test area.

Dr. John A. Hildebrand's array group developed and deployed a 3,000-m vertical array as part of an acoustics experiment in the mid-Pacific. The acoustically navigated array is equipped with 50 channels capable of receiving pseudo-random coded pulses for tomographic analysis. The array also has 200 channels sampled at 250 Hz for low frequency acoustic signal and ambient noise investigations. Drs. Hildebrand and Barbara Sotirin analyzed array navigation data from a 900-m aperture vertical array. These data illustrated motions induced by wind, tide, and internal waves that perturbed the array shape.

In collaboration with Dr. Hodgkiss, Dr. Hildebrand participated in the Downslope

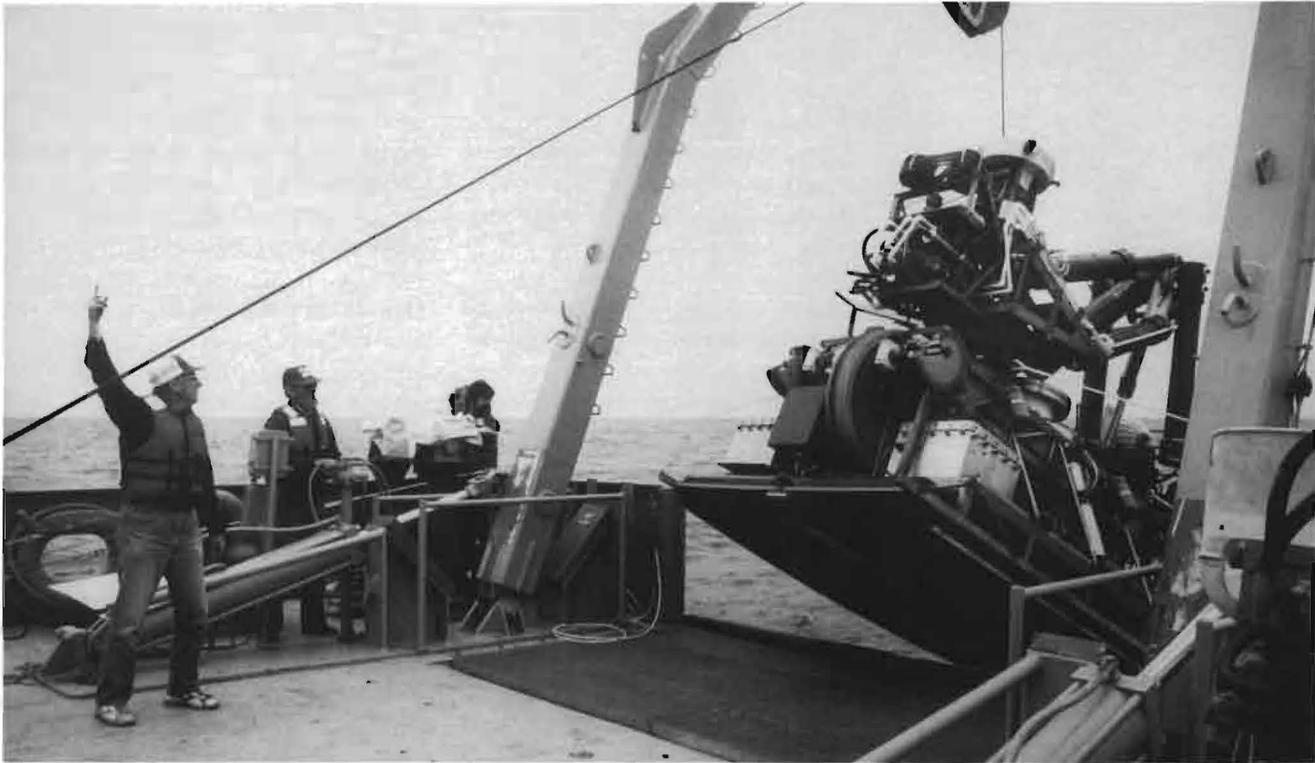
Conversion Experiment. They observed how high angle acoustic energy reflected from the continental slope is converted into low angle energy that becomes coupled with the deep sound channel. For this study a large, acoustic sound source was towed back and forth across a portion of the continental slope. Dr. Peter F. Lonsdale recently surveyed the slope with Sea Beam sonar specifically for this experiment.

Dr. Hildebrand conducted another experiment as part of the Acoustic Transients Accelerated Research Initiative, which consisted of a deep-water component and a shallow-water component. A selection of transient signals (short-duration waveforms with broad spectral content) was transmitted for reception by the R/P FLIP array in the first component. For the second component a bottom-moored vertical array in

the vicinity of the downslope source tows was used.

Drs. Hildebrand and Fred N. Spiess led scientists in a study of the earth's gravity field both on the sea surface and sea floor. Using their newly developed instrument package that houses a La Coste and Romberge gravity meter, they have acquired sea-floor gravity data from numerous locations in the eastern Pacific. These data will increase understanding of the structure of the earth's crust under the ocean. In conjunction with Dr. Spahr C. Webb, the La Coste and Romberge gravity meter was used for seismic measurements, and studies of ground motions induced by pressure signals produced by very long wavelength (hence low frequency) ocean waves.

Two shipboard gravity meters have been used with the sea-floor meter to sample vertical and lateral variations in the gravity field. Dr. Hildebrand surveyed the Axial Volcano (46°N, 130°N) on the Juan de Fuca Ridge with a shipboard meter and the bottom meter. This allowed the near surface density structure and the deep structure to be mapped simultaneously. Graduate stu-



Marine Physical Laboratory

dents J. Mark Stevenson and Philip T. C. Hammer, and Dr. Hildebrand used Dr. Robert L. Parker's ideal-body theory to place limits on the density variation required to account for the observed gravity anomalies.

The MPL gravity group is also looking into possible modifications of Newton's law of gravity. Dr. Mark A. Zumberge, Dr. Hildebrand, and colleagues are using a suite of gravity measuring devices to map the variation of gravity with depth in the ocean. They plan further ocean surface and ocean bottom observations, and anticipate taking measurements in the water column. Error estimates indicate that the completed surveys may be the best geophysical determination thus far of the Newtonian constant of gravitation, G .

Drs. Hildebrand and LeRoy M. Dorman and Hammer have deduced the internal seismic velocity structure of Jasper Seamount by seismic tomography. This technique measures multidirectional-acoustic travel times to infer an object's interior structure. To study the seamount, small explosions were detonated on the sea floor to generate sound sources, and the signals

were recorded by ocean bottom seismographs. The very high accuracy required in both position and travel time measurement was achieved using the Deep Tow navigation and positioning system developed by MPL scientists.

Dr. Dorman and graduate student Anthony E. Schreiner have demonstrated that Stoneley waves are the main source of seismic background noise on the deep-sea floor in the 0.4–5 Hz frequency range. The noise energy, generated at the sea surface by nonlinear interactions between ocean waves, spreads to the sea floor as a near vertically traveling acoustic wave and is then scattered into the sea-floor wave guide at the boundaries of sedimented regions. This was concluded by examination of the coherence of seismic noise as a function of frequency and the distance between sensors. The coherence data show that the wavelengths are very short and are consistent with Stoneley wave propagation. The relative amplitudes between the several modes show that the energy was scattered into the waveguide at distances of 20 km or less from the point of observation.

A 15-instrument, passive seismic array was deployed together with an active-source electromagnetic sounding device as part of a joint experiment by Drs. Webb, Charles S. Cox, and Steven C. Constable. Dr. Webb also tested a transient electromagnetic sounding system in the Straits of Georgia using both a magnetic source and a coil receiver. This system, constructed under the guidance of a Canadian researcher, was used to study the electrical conductivity of the upper tens of meters of the sea floor.

Dr. Christian P. de Moustier and a Duke University researcher continued work on sea floor acoustic backscatter. They developed a processing method for acoustic data recorded with a multibeam echo-sounder, which provides clues to sea-floor characteristics such as bottom roughness and bottom type. In addition, Dr. de Moustier used his acoustic data acquisition system to record volume reverberation data over Fieberling Guyot during leg 18 of the Roundabout Expedition aboard RV *Thomas Washington*. He uses the multibeam technology to track deep scattering layers in the ocean and to determine if they



can be used as tracers of the water mass dynamics about the seamount. During leg 18 of Roundabout Expedition the shallow-towed SeaMARC II sidescan sonar system and the Sea Beam multibeam echo-sounder were deployed simultaneously. The SeaMARC II system provides sidescan imagery over a swath 10 km wide and bathymetric data over a swath width about 3.4 times the water depth.

Dr. Lonsdale participated in a series of geological dives in the French research submersible *Nautilus* on the East Pacific Rise to depths of 5,400 m. This was part of the geology and tectonics study of this region, which has included Deep Tow, Sea Beam, and magnetic surveys during the past 10 years. The French diving program was focused on the floor and 4-km-high walls of Hess Deep, a slowly opening rift valley that intersects the East Pacific Rise and exposes basal layers of its crust. The 20 dives sampled young gabbroic rocks from these layers and ultramafic rocks from the top of the underlying mantle, beneath the "moho" that crops out on the sea floor.

During this past year MPL's third generation Remote Underwater Manipulator (RUM III), designed, fabricated, and operated under the direction of Dr. Victor C. Anderson, was used in two major sea tests. The first took place in the Catalina Basin in water 1,000 m deep. RUM III was operated from the research platform ORB, which was moored on station for four weeks. The Catalina test trip evaluated techniques for the National Oceanic and Atmospheric Administration resedimentation project. This NOAA program will investigate the environmental impact of manganese nodule mining of the deep sea floor benthic environment. Using the manipulator arm of RUM III, box cores were inserted into the sea-floor sediment, and various measured quantities of a sediment slurry were pumped into the open box cores. After two weeks RUM III returned to the site and recovered the box cores. It then brought them to the surface where a team of biologists checked mortality rates of organisms in the box core sediments.

The second operation was an engineering test for the mid-ocean deployment of

RUM III, which took place in 3,800-m deep water west of Cortez Bank. RUM III was reconfigured to operate from an oceanographic ship, in this case *R/V New Horizon*. This involved conversion of the telemetry system to accommodate the limited information handling capacity of a longer umbilical cable, and reduced television viewing to a slow-scan system with updated images every four seconds. A modified cable-tensioning system has increased capacity and provides a softer spring characteristic. Incorporating this into the shipboard path of the electromechanical umbilical cable has greatly simplified handling the vehicle through the water-air interface where severe surging can occur. The successful deployment of RUM III from an oceanographic ship and its operation on the deep sea floor provides oceanographers with a new deep-sea research tool.

Dr. Robert Pinkel's Upper Ocean Physics Group analyzed data from previous cruises and participated in a major experiment (CEAREX) in the eastern Arctic. From an ice camp at 83°N, 10°E, 320 km north of the Islands of Svalbard, the group monitored the ocean velocity field under the ice with a 161-kHz Doppler sonar. The sonar's configuration provided both a pulse-to-pulse coherent mode, for a short-range (30 m) high-resolution look at the details of under-ice motion, and the more conventional incoherent mode, measuring to 500 m. The internal wave field had an energy level comparable to the open Atlantic Ocean, but 10–100 times more energetic than earlier measurements of western Arctic, far removed from open water. Once an open ocean bore passed under the camp, depressing the thermocline by 100 m over a two hour period. A small Arctic eddy also drifted through the viewing region of the sonar.

The Optical Systems Group directed by Richard W. Johnson, has been developing and operating two automatic imaging systems, which assess the local visibility and total cloud cover. These devices can be included within fully automated weather observation systems, and can collect high resolution cloud cover, and cloud distribution statistics. The cloud data base can validate

simulation and analytically based predictive models of earth-to-space, cloud-free paths of sight, cloud-free intervals along selected arcs, and their associated spatial and temporal statistics. Group researchers have assembled, calibrated, and installed the cloud monitoring systems at seven different sites in California, New Mexico, Montana, Missouri, and Florida. Visibility systems are operating at MPL and Boston, Massachusetts. As the cloud field data base increases about 3,000 images per day per site, data base management and quality control procedures are being updated to insure maximum data retrieval and application reliabilities.

Dr. Frederick H. Fisher and a colleague are investigating the effect of pressure on sound absorption in MgSO₄ solutions at freezing temperatures in the deep ocean down to 10,000 m. This information is needed for designing shipboard sonars and towed high frequency side-scan sonars for range considerations versus power and frequency. The data are also used for calibrating scattering strengths of bottom topography for quantitative measurements with swath bathymetry systems.

Earlier laboratory measurements on seawater at pressures near 3,000 m indicated a larger pressure effect at 0°C than at 25°C. The 100 liter titanium resonator could not be used at higher pressures. Because measurements concern only absorption caused by the magnesium sulfate relaxation, researchers can only measure the pressure effect on 0.5 molar solutions of MgSO₄ in resonator cylinders capable of reaching the higher pressures. In fact, it is such data at 25°C that provide the basis for current predictions at depths greater than 3,000 m. Measurements were made in the 100-kHz region at about 0°C in both magnesium sulfate and sodium sulfate solutions. The latter solution is a nonabsorbing solution with the same velocity as the magnesium sulfate solution. In this way corrections for the wall losses caused by the resonator can be made.

Preliminary results indicate that mode interferences (steel versus liquid) at low pressures were severe enough that only data from 700 bars to 1,300 bars were valid.



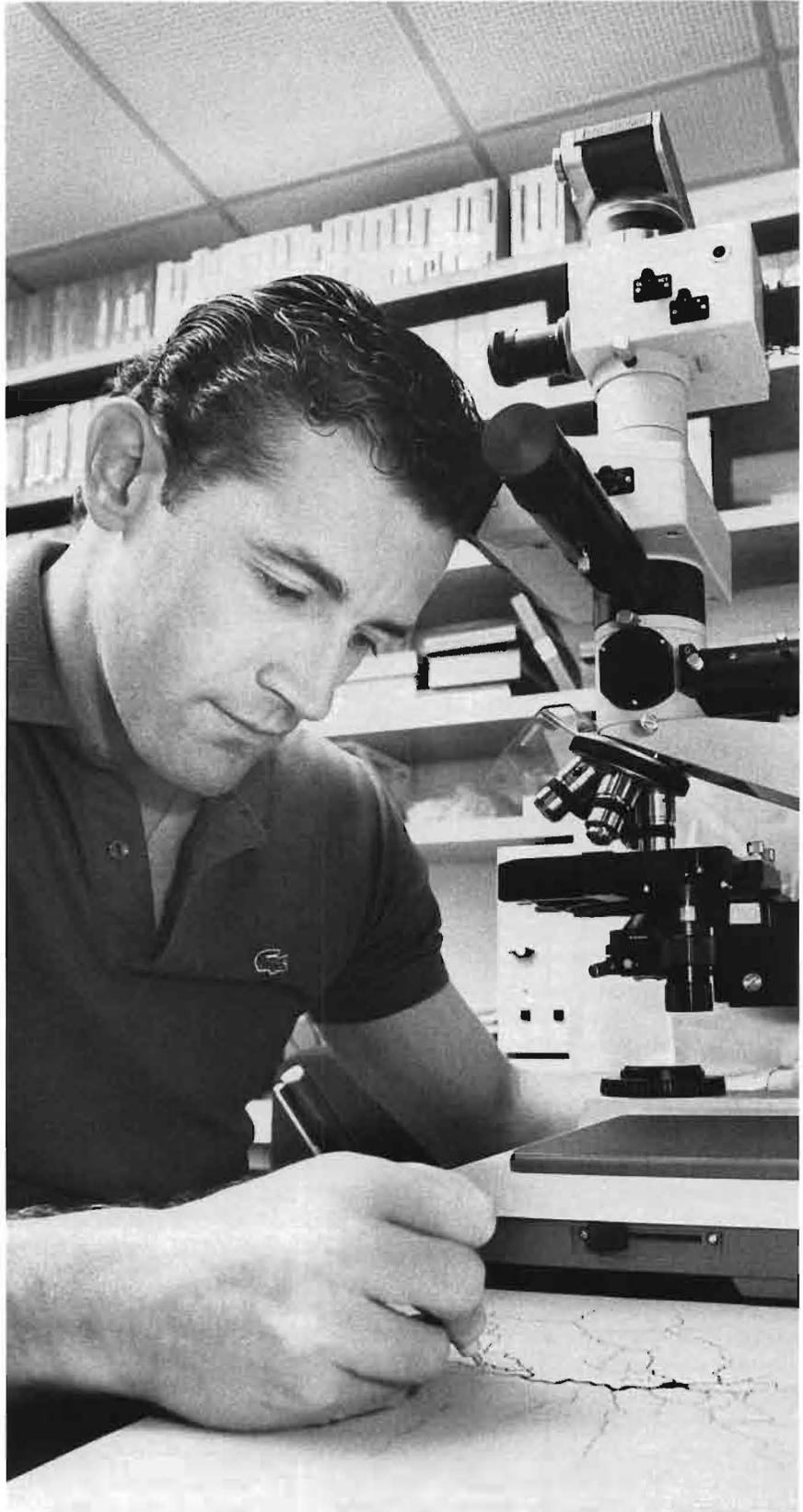
NEUROBIOLOGY UNIT

THE LABORATORIES COMPRISING the Neurobiology Unit at Scripps focus on the structure and function of the nervous system in animals, particularly bony and cartilaginous fishes.

This year the laboratories of Drs. Theodore H. Bullock and R. Glenn Northcutt included 25 graduate students, postdoctoral fellows, and visiting researchers. Drs. Bullock and John G. New and graduate student completed a survey of the electrophysiological signs of brain responses to visual stimuli in fishes. Dr. Bullock and a colleague also mapped the distribution of a new measure of synchrony in electrical activity in the brains of rays, reptiles, and mammals.

Scientists in Dr. Northcutt's group, which included Drs. Jiakun Song, Shaun P. Collin, Jacqueline F. Webb, and Helmut Wicht, used anatomical tracing techniques, embryology, and electron microscopy to focus on the evolution of visual, auditory, and lateral-line structures in the brains of fishes and amphibians.

Also included in the Neurobiology Unit are the laboratories of Drs. James T. Enright, Walter F. Heiligenberg, and Adrianus J. Kalmijn. Dr. Enright's group studies the relationship between visual perception and oculomotor performance. Dr. Heiligenberg's group uses anatomical and physiological techniques to focus on communication and social behavior in electric fish. Dr. Kalmijn and his associate employ a controlled environment to study electromagnetic detection capabilities, and hydrodynamic and acoustic perception in elasmobranch fishes.



Dr. Shaun P. Collin using a drawing tube attached to a compound microscope traces the dendrites of a labeled ganglion cell in the lamprey retina.



Dr. Warren B. White and Ted Walker examine synoptic sea level height maps of the California Current region. These maps were obtained by assimilating altimetric sea level height data (from the satellite shown in the accompanying schematic figure) with model sea level height data.

OCEAN RESEARCH DIVISION

THE OCEAN RESEARCH DIVISION (ORD) will cease to exist July 1, 1989. Its personnel and activities will be distributed among three new divisions and several existing ones, a consequence of a Scripps reorganization. During its final year ORD continued to encompass a variety of marine science investigations including climate research, marine biology, marine chemistry, physical oceanography, and marine physics. Here, three examples of ORD programs are discussed.

Repeated High Resolution Sections from Volunteer Observing Ships

Drs. Dean H. Roemmich (MLRG) and Bruce D. Cornuelle have collected closely spaced temperature profiles along a commercial ship track in the central Pacific Ocean for three and one-half years. A scientist goes on board a commercial ship four times per year to deploy deep expendable bathythermograph (XBT) probes. These measure the temperature structure in the upper 850 m of water between Auckland, New Zealand, and Honolulu, Hawaii. As part of the project, an automatic XBT



launching and control system has been developed and is now in use.

Hydrographic station data form the basis for information about the general ocean circulation. Because of the high cost of using research vessels few ocean-scale hydrographic sections exist, and only a handful of these have ever been repeated. Very little is known about the variability of large-scale ocean currents and gyres observed in these single-snapshot transects. Scientists know the ocean plays a role in climate through heat redistribution by ocean currents and that the ocean circulation may be crucial in moderating short-term climate

variations and global trends. To describe the evolution of the atmosphere/ocean system, it is now necessary to gain more knowledge of oceanic variability. The repeating XBT transects in the central Pacific measure the variability of ocean temperature and currents ranging from small, rapidly evolving eddies, 50–300 km across, to the slow evolution of the gyres that span the ocean basin.

Drs. Warren B. White and David L. Cutchin head a large volunteer observing ship network for the Pacific. Through this program, navigation officers on board participating merchant vessels drop two to



Components of an experimental nowcast/forecast model of the California Current proposed for implementation this next year. (Upper map) Wind stress data used to drive the model. (Second map) Sea level height field obtained from the wind-driven model. (Third map) Altimetric sea level height obtained from satellite. (Lower map) Updated model sea level height field after assimilation with satellite sea level height data.

four standard XBTs per day to obtain broad-scale data on the ocean's temperature structure to a depth of about 400 m. The closer spacing and greater depth capabilities of the Roemmich/Cornuelle high-resolution survey complements the existing broad-scale sampling. During the World Ocean Circulation Experiment (WOCE) in the 1990s, scientists plan to expand the high resolution survey to include additional ships crossing the Pacific on widely separated north-south and east-west lines, with the broad-scale survey providing information in areas between high resolution sections.

The Blue Star Line's *M/V Southland Star* was a key factor in implementing the idea of repeated sections. The ship runs regular container service on a route that includes legs between Suva, Fiji, and Auckland, New Zealand, and between Auckland and Honolulu, Hawaii. These legs cross important features of the subtropical gyre of the South Pacific and the strong zonal current system of the tropics. The Blue Star Line was willing to allow a scientific observer on board *M/V Southland Star*, and observations began in March 1986, with Drs. Roemmich and Cornuelle dropping hourly probes every 35 km between Auckland and Suva.

The hourly schedule—uncomfortable for one person—fueled the development of the prototype autolauncher. The launcher drops up to 12 probes at preselected times without reloading. Probes are dropped when the computer activates a solenoid that releases a trap door. The computer monitors each XBT as it falls, logs the data, and sets off an alarm in the event of an instrument malfunction. Between launches, the computer is used to calculate probe positions from the ship's satellite navigation

data, to edit the temperature profile data semiautomatically, to plot sets of casts, and to contour the section.

Fine wire used in the probes can be blown against the ship causing breakage or insulation damage. Thus the launcher is placed away from prevailing winds near the ship's stern, which significantly increases data return. Minimizing ship contact also increases the success rate. Stern-launched XBTs have a success rate 25 percent higher than bridge-launched XBTs when the autolauncher is used. The system is now reliable enough that the observers' duties have sometimes been assumed by graduate students like Phillip J. Sutton, who ran the system for two successful legs.

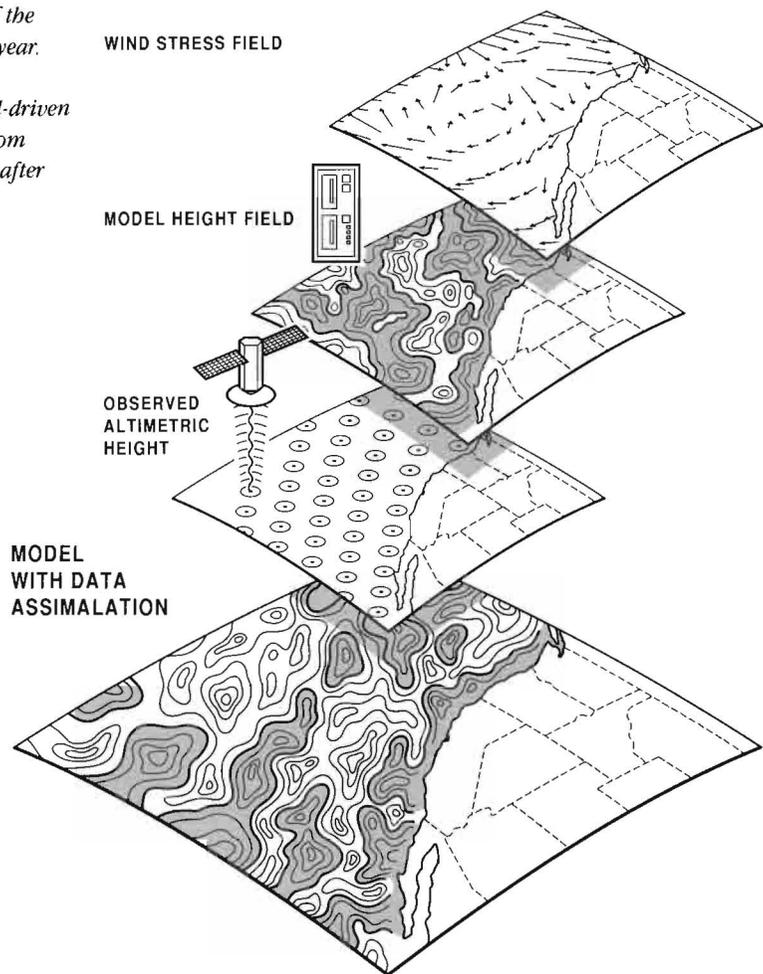
Scientific analysis of the *Southland Star* data set already has shown that large scale currents do move and evolve substantially over months to years. These evolving cur-

rents carry with them the huge pools of warm water in the tropics, which are known to have a strong influence on the overlying circulation in the atmosphere. Without the cooperation of the Blue Star Line, this work could not proceed.

Experimental Ocean Prediction in the California Current

Drs. White, Chang-kou Tai, and Alejandro Pares-Sierra are developing an experimental ocean prediction system for the synoptic circulation in the California Current, not unlike Weather Service predictions for the synoptic weather conditions over the Northern Hemisphere. Such a capability will allow biweekly or monthly maps of mesoscale eddy activity in the California Current to be produced for scientists and operational personnel nationwide.

The California Current was chosen be-





cause the statistical and phenomenological nature of this region's synoptic ocean circulation is better documented than most. The current has been intensively studied for 40 years by scientists at Scripps and other west coast institutions. Simultaneous examination of both in situ and remotely sensed data has resulted in elucidating the meso-scale eddy activity in the California Current. Drs. Pares-Sierra and Geoffrey K. Vallis developed a realistic, wind driven, eddy resolving prognostic model of the California Current for use in this study.

This California Current model has about 10-km resolution, with layers that allow both baroclinic instability and upwelling to be simulated. Also represented are the effects of bottom bathymetry and coastline topography on the synoptic circulation of the current. This model, driven by synoptic wind stress, reproduces many of the mean and statistical aspects of the synoptic meso-scale circulation in the California Current. However, without additional information, it cannot simulate the phase of the mesoscale eddy activity. Therefore, a package allowing assimilation into the model of GEOSAT Exact Repeat Mission (ERM) altimetric sea level information has been developed, thus defining mesoscale eddy activity in the model. While only sea level information is being assimilated, the projection of the internal baroclinic structure of the model ocean onto the sea surface allows the sea-level information to prescribe the internal synoptic circulation of the upper 500 m of ocean almost as well as the surface synoptic circulation.

Studies of Ocean Circulation Using Satellite-Tracked Drifters

Ocean surface circulation patterns were traditionally compiled by observing floating objects, usually the drift of ships. With satellite techniques for radio location (the ARGOS system from polar orbiting satellites) has come the possibility of accurate measurement of global flow patterns by tracking drifters. Drifters are devices with a surface float carrying a radio antenna and a drag producing device (drogue) tethered to enhance the water-following capability. The largest mass deployment of ARGOS-

located drifters was in the southern oceans as part of the First Global GARP Experiments. There 300 floats were released to measure atmospheric pressure for improving weather prediction models. Dr. Pearn P. Niiler has designed and used a new generation of ocean drifter for which the water-following characteristics are more accurately known and which cost much less to manufacture and deploy.

The satellite-tracked drifter development at Scripps is unique because the "slip" of the drogue through water has been accurately measured with Vector Measuring Current Meters (VMCMS) mounted on the drogue. Drs. Russ E. Davis and Lloyd A. Regier have collaborated with Dr. Niiler on this aspect of the project, providing the calibrated VMCMS and insights into drifter design and data interpretation. A San Diego company has also been involved in design, at-sea tests, and drifter manufacturing. With these new drifters, water motion at approximately 15-m depth and surface water temperature are measured. Special data lines can be added to the drifters so variables such as subsurface temperature, biological fluorescence, and salinity can be remotely measured. Atmospheric pressure measurements will be added to the surface float. The instruments, packaged in a soluble cardboard box, are self-deployed as the box disintegrates.

During an equatorial Pacific cruise the drifters were calibrated for slip past the drogue element under varying wind conditions and drag area ratio, R (the ratio of the drag for drogue to surface float plus tether). Results indicate $R > 50$ is required to restrict errors to within acceptable limits ($< 2 \text{ cm sec}^{-1}$). A model has been developed that provides slip past the drogues as a function of wind speed and R for the range of speeds near the equator.

Drs. Niiler, Jeffrey D. Paduan, and Mark S. Swenson are analyzing drifter data and deploying additional drifters. The versatility of the drifters is revealed in three experiments in which they were deployed.

In the Coastal Transition Zone Experiment clusters of drifters (46) were used to "tag" offshore-flowing cold-water filaments off the California coast. These features have

small scales of a few tens of kilometers in the cross-filament direction but extend many hundreds of kilometers offshore. The drifter trajectories are useful in directing research vessels to the filaments when clouds block the sea surface from the satellites' view. Beyond that, individual drifters measure velocity and temperature, and they measure the deformation of clusters of drifters that exposes dynamical balances within the jets.

In a second study 49 drifters were deployed with other moored instruments and ship surveys in the North Pacific for the Ocean STORMS Experiments. As the array dispersed and drifted with the mean flow, it mapped out current and temperature fields over hundreds of kilometers. Time and space scales of roughly 1 week and 50 kilometers were dominant for velocity. Temperature scales were longer and larger (1 month and 200 km). The combination of temperature and velocity from the drifters provides a unique look at the region's balance of heat. Horizontal advection rate of heat, averaged over the array for the entire fall period, is as important as the local heating rate. Combination of drifter velocity with wind measurements shows Ekman flow to be dominant for 5-to-20-day period motions.

As part of Tropical Ocean Global and Atmosphere's Pan-Pacific Experiment, with the aid of Dr. Cutchin, a population of more than 200 drifters is being maintained from Scripps Volunteer Observing Ships in the tropical Pacific. The goal is to map surface circulation and its variability over global scales with concentration on that unique region as part of WOCE.

Drifter measurements provide data following fluid parcels; this can be exploited to estimate terms in oceanic heat and energy balances. The decorrelation time scales of the measurements are many times shorter than their moored counterparts; this fact provides for more independent estimates of velocity than can be obtained from current meters in the same time. These qualities, combined with lowered unit costs and improved accuracy, insure that drifter measurements will be an increasingly important oceanographic tool.



PHYSIOLOGICAL RESEARCH LABORATORY

SCIENTISTS IN THE Physiological Research Laboratory (PRL) concentrate on the behavioral, physiological, and biochemical adaptations of aquatic and terrestrial animals. In this report the physiology of swimming sharks, bubble formation in fishes, and the diving physiology of birds and mammals are discussed.

Shark Swimming Performance and Physiology—The Comparative Biomedical Perspective

Dr. Jeffrey B. Graham continued his studies of the performance and cardio-respiratory adjustments of swimming sharks. He and graduate student Heidi Dewar determined that the O_2 consumption of a swimming shark is similar to that of other active fishes. They also found that the leopard shark has a critical swimming speed—an index of aerobic capacity—only slightly less than that of a salmon. Through studies of cardiac performance and blood- O_2 transport in swimming sharks, graduate student N. Chin Lai showed that cardiac stroke volume is more critical in elevating



Graduate student Heidi Dewar attaches white markers to the dorsal midline of an anesthetized leopard shark for video analysis of swimming motions.



Specialized mirror attachment on the water tunnel permits simultaneous top and side view video recordings of shark movements during swimming. Records are digitally analyzed for kinematic analysis.

cardiac output than is heart rate. Lai found that pericardial pressure rose during swimming. This finding challenges the long-held idea that negative pressure is needed to fill the heart. Also pressure, echocardiography, and angiography all show that—contrary to earlier ideas—blood enters the ventricle during early and late diastole and not just during atrial systole.

Visiting scholar Dr. M. Christopher Barnhart continued investigations of metabolic regulation in dormant mollusks. These studies provided the first direct evidence that respiratory acidosis plays a role in metabolic depression during dormancy and may play a similar role in hibernation and sleep in mammals. These results were discussed at a recent international symposium on hibernation and dormancy “Living in the Cold II,” April, 1989, Strasbourg, France. Dr. Barnhart continues to elucidate the effects of CO₂ on cellular metabolism using *in vitro* preparations.

Bubble Formation in Animals

Dr. Edvard A. Hemmingsen and graduate student Wendy L. Ryan continued to investigate the role of hydrophobic surfaces in the formation of bubbles in both liquids and organisms. They are studying the degree to which such surfaces facilitate the spontaneous nucleation of bubbles in the absence of any gas micronuclei. This may be a pertinent phenomenon during activity, when tensile forces can be generated in internal fluids in many locations. Previous studies by Dr. Hemmingsen and colleagues have shown that gas micronuclei rarely exist in cells or relatively simple animals. These earlier studies strongly indicate that *in vivo* bubbles originate from nucleation sites that are generated spontaneously. The long-range objective of Dr. Hemmingsen's investigations is to clarify the processes that lead to bubble disease in fish and to decompression sickness in humans.

Diving and Exercise Physiology in Birds and Mammals

The studies in Dr. Gerald L. Kooyman's laboratory are focused on the adaptation of higher vertebrates to life at sea. Drs. Kooyman and Paul J. Ponganis, and Dr. Mark H. Zornow, UC San Diego, conducted studies of the cardiovascular responses of seals to heavy exercise. The field work was conducted at three sites. A team of six investigators led by Dr. Kooyman traveled to the Antarctic to study physiological responses of seals and penguins to diving under natural conditions. The team included Dr. Ponganis, several U.S. researchers, and a French scientist.

Dr. Kooyman, graduate student Joseph Slovacek, and a Brigham Young University student joined a French scientist at the French subantarctic base in the Crozet Archipelago to study the hunting behavior of king penguins. Graduate student Donald A. Croll completed his study of diving and energetics of the thick-billed murre at Coats Island, Canadian Arctic, where he collaborated with a Canadian wildlife biologist.



CENTER FOR COASTAL STUDIES

SCIENTISTS AT THE Center for Coastal Studies, under the direction of Dr. Clinton D. Winant, engage in worldwide studies of the coastal environment, the development of data acquisition systems and research instrumentation, and advising on coastal protection and sediment management.

Each year this report features one of the working groups at the center. This year the work of the Shore Processes Group, headed by Dr. Robert T. Guza, is discussed. Dr. Guza's group focuses on fluid-sediment interactions, nearshore waves and currents, and shoreline changes associated with construction activities.

Dr. Guza's group continues to refine and expand its capabilities to measure nearshore surface gravity waves and wave-induced currents particularly in the surf zone. Many theoretical and conceptual advances have resulted from insights gained through field observations of the extremely complex nearshore fluid dynamics. The group uses arrays of sensors to determine the propagation directions of waves, and to observe spatial variations caused by wave breaking or bathymetric features.

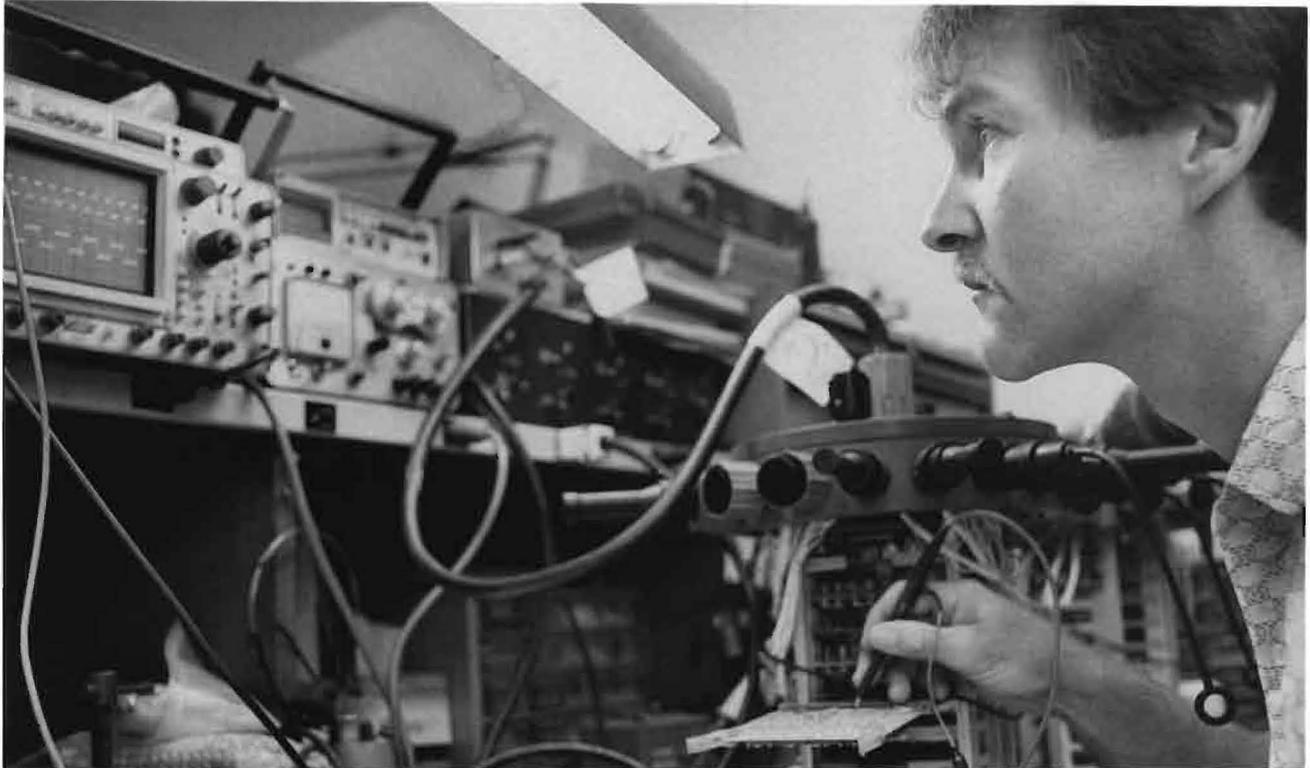


Paul J. Harvey secures a data acquisition package in anticipation of heavy weather.

K. Millikan



William A. Boyd performs timing verification on an underwater data acquisition system.



Open frame electromagnetic current meters, developed and produced at Scripps, have progressed from the research and development phase and are now routinely used in the field. Group scientists are developing a Doppler acoustic flow meter tailored specifically to shallow water measurements under shoaling waves. A multi-level, run-up meter, with multiple resistance wires deployed at 5-cm increments above the sand, appears capable of characterizing the shape of broken waves traversing the beach face. Buried pressure sensors deployed in transects across the beach face have yielded both pressure records of individual waves passing over the sand and time series of the shape and level of the water table as the tide ebbs and flows. Scientists use buried sensors to measure the energy of major storms because other surf zone instrumentation cannot survive. However, the interpretation of such data is complex because the geotechnical dependencies such as sand grain size, aeration, and elasticity are not well understood.

The group has developed data acquisition systems (high density encoders) that

can collect up to 32 analogue channels each at a single underwater "junction box." These systems then send the digitized, multiplexed data stream to shore via a single cable or radio link. Once on shore the data are recorded on magnetic tape, and/or reviewed in near real time. The ability to quickly analyze data allows reconfiguration of the instrument arrays to accommodate unanticipated conditions, or to identify and replace faulty sensors.

Prototype testing and precise instrument calibration are made possible by facilities such as the stratified flow channel and the temperature/pressure calibration bath at the Hydraulics Laboratory. Current positioning methods for diver deployed instrumentation use pre-cut cables to triangulate positions between instruments, with accuracies near one percent. Because these underwater "kites" are labor intensive and require skill to deploy, a diver-held acoustic positioning system is being developed.

These technological advances have resulted in more extensive data sets. In turn, more sophisticated analysis is needed to test the accuracy of modeling theories of

circulation and wave propagation in the nearshore region. Graduate students, under Dr. Guza's direction, are working on the development and application of such analysis techniques.

These densely instrumented, accurately positioned wave arrays also provide high quality wave information to other researchers working on applied coastal problems. Dr. Guza's group has recently deployed arrays at Norfolk, Virginia, to gather ground-truth data for modulation of radar backscatter by sea and swell. They also are using the arrays at Cape Canaveral, Florida, to study reflections of wave energy by artificial bars and at Isles Dernieres, Louisiana, to measure the erosion of barrier islands. Each of these experiments involves researchers from several other academic institutions.

Dr. Guza's group will participate in a major multi-investigator experiment at Duck, North Carolina. They will also take part in the instrumentation of the Southern California Bight to investigate the effects of island and shoal sheltering on wave energy striking the southern California coast.



GEOLOGICAL RESEARCH DIVISION

STUDIES IN THE GEOLOGICAL RESEARCH DIVISION (GRD) cover a wide range of scientific areas from the deep earth to the ocean, atmosphere, and outer space. This year's report includes several examples of these research activities.

Boron Isotopes

Dr. Arthur J. Spivack's research focuses on the exploitation of the light stable isotopes of boron for a range of geochemical and oceanographic problems.

The large variations in terrestrial boron isotope ratios make them sensitive indicators of many geological processes. Unlike hydrogen, carbon, and sulfur, the isotope geochemistry of boron is in its infancy. A major part of Dr. Spivack's efforts is centered on developing the fundamental aspects of this field, which involves characterizing the isotopic compositions of the major terrestrial reservoirs and quantifying how different geological processes fractionate the isotopes. Investigations of the interaction between seawater and the oceanic crust and sediments are being given special



Dr. Arthur J. Spivack works on chemical preparation of a geologic sample for boron isotope analysis.



Dr. Timothy D. Herbert analyzes Cretaceous sediments for calcium carbonate content.

Opposite page: Closely spaced samples of deep-sea limestones from central Italy are prepared for analysis.

emphasis. His preliminary work has demonstrated that exchanges between these reservoirs are the driving force behind large-scale terrestrial isotopic variations. He also found that the boron isotopic signature imprinted in the oceanic crust during its interaction with seawater may be a useful tracer of volatiles that are subducted into the mantle. Sections of the oceanic crust collected both in situ by drilling and dredging and from ophiolites on land are being studied to develop the boron isotope anatomy of the oceanic crust. The isotopic analyses are performed with thermal ionization mass spectrometry, careful attention being paid to minimizing contamination. Sample preparation is carried out in a newly constructed clean laboratory.

Ancient Climate Change

Dr. Timothy D. Herbert uses several methods to explore the record of climate change preserved in marine sediments. He is working on improving methods of quantifying rates of climate change in the geologic record of the past 120 million years and elucidating the driving forces behind



the large changes observed. “Milankovitch cycles”—periodic changes in insolation—have driven glacial cycles in the late Pleistocene, and celestial mechanicians calculate that past insolation perturbations have occurred at nearly the same frequencies and magnitudes. Thus oscillations in the geologic record in the frequency band of 10^4 to 10^6 years can be read as a natural climate sensitivity experiment with nearly constant external forcing, but with changes in internal conditions such as plate positions, inter-oceanic connections, or atmospheric CO_2 concentrations. Contrary to the prevailing view that large ice sheets are required to introduce necessary internal feedbacks to radiation variations, Dr. Herbert and colleagues have found that even warm climates are surprisingly sensitive to orbital perturbations.

Orbital signals in sediments offer time signals of at least an order of magnitude shorter duration than conventional dating methods; improved chronologies would allow much more detailed and realistic reconstruction of the dynamics of past changes in the ocean. Because the time-

series approach to the study of paleoclimates requires large amounts of data from closely spaced sediment samples, Dr. Herbert is experimenting with techniques to acquire data by rapid, automated means. Image analysis and porosity data have given useful proxy records of carbonate content, a major variable subject to orbital modulation. Future work will focus on refining measurements of other sediment components of climatic interest, such as quartz, opal, and clay minerals.

Alvin Dive Programs

Several GRD researchers continue work on materials collected in a series of submersible dives in the Mariana Trough, a back-arc basin in the western Pacific. Drs. Harmon Craig, Peter F. Lonsdale, and James W. Hawkins served as chief scientists of various expedition legs. They were joined by Drs. J. Douglas Macdougall and Alan M. Volpe, and graduate student Laura B. Stokking. On shore, work also involved Dr. Miriam Kastner and graduate student Anne A. Sturz.

Work at sea focused on the axial ridge of

the Mariana Trough near 18°N , with dives navigated in a transponder network. Scientists on these dives used detailed charts based on multibeam echo-sounding and previous Deep Tow studies. Active hydrothermal vents were found in the axial region, and several proved to be high-temperature “clear smokers.” A chimney recovered from one of the vents has been studied in detail and found to consist of sphalerite, galena, chalcopyrite, barite, and small amounts of several other hydrothermally deposited phases. Chemical gradients in the chimney walls, particularly in Cu/Zn and Zn/Pb ratios, apparently reflect thermal and chemical gradients across the walls. At the time of collection, the vent water temperature was measured at 287°C . The recovered chimney fragments resemble those dredged from the Lau Basin during the 1986 Papa-Tua Expedition.

The relationship between sea-floor morphology and rock type was the researchers’ focus during the second dive series. Studies of the Mariana Trough samples have shown a close correlation between sea-floor depth and the degree of chemical



evolution of the lavas found on the axial ridge. Those from the deeper depths are relatively more primitive and have higher eruption temperatures. The fine-scale sampling accomplished with the submersible permitted careful study of the degree and scale of trace element and isotopic variations. In particular, the discovery on the axial ridge of both mid-ocean-ridge-like rocks and island-arc-like samples in close proximity to one another has increased understanding of the evolution of back-arc basins and of oceanic crust formation.

Roundabout Expedition

Dr. James W. Hawkins and several graduate students took part in two legs of Roundabout Expedition aboard R/V *Thomas Washington*. Scientists on leg 14 left Suva, Fiji, en route to Nuku'alofa, Tonga, to do bathymetric, magnetic, and single-channel seismic reflection profiling in the western Lau Basin. They were surveying potential drilling sites for the Ocean Drilling Program, and they found suitable areas for three of the proposed sites.

Researchers on leg 15 of the expedition left Tonga en route to Pago Pago, Samoa, to continue bathymetric and magnetic surveying and to dredge rocks for geochemical study. The surveys charted the actively spreading axial ridge and rock samples were collected along the neovolcanic zone. A seamount that had been split into two symmetric segments by the axial rift and a ridge-ridge-ridge triple junction were discovered and charted. This area, which includes the hydrothermal vent site discovered on the Papa-Tua Expedition in 1986, has a variety of rock types ranging from basalt to andesite. Laboratory studies of this unusual collection indicate that the variability was created by one ridge segment that propagated into the Tonga Arc crust.

Atolls and Guyots

Dr. Edward L. Winterer also led two legs of Roundabout Expedition to study Early Cretaceous reefs in the Northwest Pacific. He collaborated with Dr. James H. Natland and two colleagues on the expedition. These reefs flourished in warm tropical waters in the South Pacific about 120 mil-

lion years ago, and then sank. The reefs are now beneath about 1,500 m of water, and have been carried by Pacific Plate motions thousands of kilometers from their place of origin, into the Northwest Pacific. Swath (Sea Beam) maps of the sunken reefs reveal many are atolls, with a perimeter reef surrounding a central lagoon. Seismic profiles show that the reef sediments are as much as 800 m thick, capping a wave-truncated volcanic seamount. The summits of many atolls are pitted by deep sinkholes, indicating that prior to final drowning they were uplifted about 200 m above sea level and partly dissolved by rainwater. The regional uplift that raised these atolls appears to correlate with a major reorganization of lithospheric plates in the Pacific about 110 million years ago. The reorganization resulted in creation of a large thermal bulge in the mantle (the "Darwin Rise") that remains in the South Pacific.

Paleomagnetic Studies

The paleomagnetic group, headed by Dr. Lisa Tauxe, pursued research along several lines. Graduate student Laura B. Stokking completed work on the characteristics of magnetization acquired during grain growth. Her experiments were designed to test the predictive accuracy of theoretical models of the relationship between the magnetic field during grain growth and the resulting remanent magnetization. In general, theoretical predictions agree with the experimental results. However, Stokking and Dr. Tauxe firmly established that the ambient magnetic field exerts a slight but measurable control on both the size and orientation of hematite grains that precipitate from solution. Furthermore, multiple generations of hematite display a quite complicated remanence behavior that cannot be predicted from theory.

Graduate student Thomas S. Pick, working with Drs. Tauxe and Gustaf O. S. Arrhenius, continued research on grain-growth magnetization using magnetite grown from green rust. His results affirm the major conclusions of the hematite based studies, but demonstrate a stronger control of crystal orientation by the magnetic field, as expected from its greater

magnetic moment.

Graduate student Jeff S. Gee, in collaboration with Drs. Hubert H. Staudigel and Tauxe, is investigating the origin of the magnetic anomalies associated with seamounts. The interpretation of such anomalies provides much of the basis for reconstruction of the Pacific plate motion with respect to the spin axis and yet, the origin of the anomalies is not clear. Gee has established the complex nature of seamount rock magnetization, which must be taken into account when interpreting the associated magnetic anomaly profiles.

Rate of Ice Ablation

Dr. Devendra Lal, Dr. James R. Arnold, and colleagues have discovered a new method for determining the rate of ice ablation. They demonstrated that ^{14}C produced in situ in ice crystals is measurable, and that its concentration can be used to determine accurately the rate of ice ablation. They measured the total ^{14}C , extracted separately with CO and CO₂ carrier gases, and showed that about half of the ^{14}C activity is present in the CO phase. It can be unequivocally demonstrated that ^{14}C arose primarily from in situ nuclear spallation of oxygen in ice crystals. The results from two sites at Allan Hills yield ablation rates of -4 and $-8 \text{ cm}\cdot\text{yr}^{-1}$, in agreement with the measurements of ice ablation rates, utilizing stakes.



Dr. Carol A. Stepien scores patterns of protein migration on a gel for biochemical genetics.

MARINE BIOLOGY RESEARCH DIVISION

MARINE BIOLOGY RESEARCH DIVISION scientists continue to investigate the molecular, biochemical, physiological, and ecological characteristics of marine animals, plants, and bacteria.

Ecological studies of the energetics of the deep-sea benthic boundary layer communities are the major emphasis in the laboratory of Dr. Kenneth L. Smith. In situ experiments are under way to evaluate the coupling between food-energy supply and community-energy demand in the deep-sea benthic boundary layer for periods of a week to a year. A camera and an acoustic monitoring station are being developed for year-long surveillance of benthic boundary layer animals in conjunction with these experiments. Graduate student Waldo W. Wakefield is completing studies on the importance of planktonic larvae of slope-dwelling megafauna in the seasonal transport of organic matter through the water column. Graduate student Ronald C. Kaufmann continues his studies of the energetics and sensory biology of abundant scavenging amphipods in deep-sea commu-



nities of the eastern and central North Pacific.

Studies in Dr. George N. Somero's laboratory focused on biochemical adaptations to the marine environment. Graduate student Allen G. Gibbs investigated adaptation to hydrostatic pressure by the membrane ion transport enzyme, sodium-potassium adenosine triphosphatase (Na-K-ATPase). He demonstrated that the protein and lipid moieties of the enzyme adapt to pressure, and that a minimal pressure of approximately 200 atmospheres is required to elicit adaptive change. A model for Na-K-ATPase structural change during catalysis was developed from these data.

In Dr. Somero's laboratory, studies of enzymes of deep-sea animals from the hydrothermal vents showed that metabolic levels of vent animals are much higher than those of typical, nonvent, deep-sea species. However, research by a visiting scientist showed that enzymes of the fishes associated with vents are not adapted to function at high temperatures. The data suggest that vent fishes may not be able to withstand high temperature vent waters for extended periods.

Graduate student Sandor E. Kaupp demonstrated major effects of temperature on the growth and biochemical properties of larval and juvenile California halibut. His



Drs. Carol A. Stepien and Richard H. Rosenblatt prepare tissue samples of fish for electrophoretic study.

Opposite page: (Left) A gel is prepared by dissolving starch in water. (Right) Extracts of tissue samples are placed in the chilled gel.

results provide important biochemical indices for estimating the physiological state of field-caught fishes. Such estimates are needed for developing models to analyze natural populations of commercially important fishes.

Dr. Joan G. Stewart completed experimental studies of processes and mechanisms within and between several intertidal algal assemblages and a description of component species. The boundary between surfgrass and algal turf appears to be mediated primarily by a combination of physical factors that restricts surfgrass to wetter habitats and by competition between *Corallina* and *Phyllospadix*. Morphology and growth rates affect changes in proportional cover of these two dominant forms. Dr. Stewart continues to study individual algal species. She is determining the scale of long-term fluctuations in relative abundances in intertidal zones.

Dr. Victor D. Vacquier's group studies proteins involved in the fertilization process in sea urchin and abalone. They have isolated a protein from sperm cells of the red abalone that makes a hole in the egg

coat. The gene for this protein has been cloned and its nucleotide sequence determined for two abalone species. They hope to obtain this gene's nucleotide sequence from several others. The group then could estimate when changes in the molecule have occurred during evolution. They have also localized, isolated, and characterized the enzyme adenylate cyclase from sea urchin sperm cells. Molecular cloning of this ubiquitous regulatory enzyme is in progress.

Dr. Benjamin E. Volcani's group investigates the mechanisms by which silicon regulates gene expression and DNA replication in diatoms. Currently, they are studying two native plasmids, pCf1 and pCf2, which they discovered in the diatom *Cylindrotheca fusiformis*. Dr. Robin W. Ord and colleagues have completed the nucleotide sequence determination of pCf2. Drs. Mark M. Hildebrand and Ord are analyzing the sequence data, which indicate that the plasmid contains six open reading frames of undetermined content. Plasmid pCf1 is being readied for sequence determination. These analyses will help determine the role



that plasmids play in the diatom cell.

Dr. George D. F. Wilson has continued his research on isopod crustaceans by collaborating with a visiting specialist on the study of several groups of Antarctic isopods, including a revision of the genus *Coperomus* and the family Acanthaspidiidae. A unique form of swimming in the benthopelagic isopod *Munneurycope* was investigated cooperatively with graduate student Michel A. Boudrias.

Dr. Wilson has started an NSF-funded project on isopod sexual biology. For this and a study of swimming functional morphology several giant deep-sea isopods (*Bathynomus giganteus*) have been maintained and observed live at the Scripps experimental aquarium. Dr. Wilson also participated in two RUM III (Remote Underwater Manipulator) test cruises to evaluate this vehicle's function for upcoming studies.

Graduate student Alexander B. P. Leonard, working on a study of the biological impacts of manganese nodule mining, has been investigating molecular approaches to identifying preserved deep-sea

crustacea. He also has aided in integrating the data from camera runs made by the Marine Physical Laboratory's Deep Tow vehicle in 1983 during Expedition Echo I. Dr. Wilson visited the Japanese National Research Institute for Pollution and Resources to work with Japanese colleagues on approaches to studying the impact of manganese nodule mining in the deep sea.

Research in the laboratory of Dr. Richard H. Rosenblatt centered on the biochemical genetics of marine fishes. With Dr. Carol A. Stepien he examined patterns of gene flow and genetic differentiation in northeast Pacific clinid fishes. Dr. Stepien studied relationships between clinid fishes of the north and south temperate regions, and concluded that the separation probably dates back to the Miocene. With colleagues from the Natural History Museum of Los Angeles County and the National Marine Fisheries Service, La Jolla, Dr. Rosenblatt has prepared a description of a new species of ophidiiform fish restricted to the hydrothermal vent areas of the eastern equatorial Pacific Ocean.

Dr. Andrew A. Benson's research activ-

ities included a cruise off British Columbia to study the biochemistry of degenerative processes in spawning salmon. The work showed that the mammalian peptide hormone of many functions, vasoactive intestinal peptide, appears to have a role as messenger in the salmon. Also, salmon calcitonin, an extremely potent calcium-regulating hormone, is shifted to the human calcitonin amino-acid sequence after spawning. The apparent functions of two genes and their gene-related peptides in salmon open a new vista in calcium regulation in fishes and possibly in humans as well. These studies were carried out with researchers from several other institutions.

Dr. Benson joined 120 Soviet scientists and crew aboard a Soviet research ship in Singapore. With two other U.S. researchers he studied coral and macrophyte productivity and ecology in the coastal waters of the Seychelles Islands. The respiration/photosynthesis relationships of the predominant seagrass, *Thalassodendron*, were studied by using $^{14}\text{CO}_2$ and oxygen electrode techniques.

In the laboratory, Dr. Benson has identi-



fied a precursor of arsenobetaine, the major arsenical component of lobster, shrimp, and many oceanic fishes used for food. This compound, trimethylarsoniumribosylglycerolsulfate, can be converted metabolically to arsenobetaine. Arsenic metabolism is important in tropical and other low-nutrient surface waters of oceans where the simple ion, phosphate, is depleted.

Dr. Lanna Cheng continues to study the ecology of *Halobates*, the only insects known to inhabit the open ocean. Research on a series of samples collected by Dutch colleagues in the Banda and Arafura seas revealed that population density of *Halobates germanus*, the predominant species in the samples, was inversely related to surface chlorophyll concentrations. Efforts will be made in future expeditions to confirm these findings and to determine what other factors may control the population densities of ocean-skaters.

Dr. Francis T. Haxo, in collaboration with three international scientists, attributed the bright blue integumentary coloration of the starfish *Linckia laevigata* to the presence of a unique carotenoprotein (linckiacyanin), which has as chromophores both conventional astaxanthin and a novel aromatic carotenoid. This study suggests that the high near-ultraviolet absorbance peak observed in linckiacyanin is caused by exciton-exciton interaction between carotenoid molecules, rather than expected absorption by labile cis-isomers.

Since Dr. Ralph A. Lewin discovered and described the prochlorophytes—a new sub-class of algae—more than 10 years ago, research on the symbiotic *Prochloron* has proceeded along many fronts, although pure cultures are not yet available. With the discovery of a second genus, *Prochlorothrix*, in Dutch lakes, comparative studies have become possible, and considerably facilitated now that pure (axenic) cultures have been obtained. Study of the common marine flagellate genus *Tetraselmis* has been extended to include determinations of the cellular DNA. This work was facilitated by a DAPI-fluorescence technique for in-situ determinations, which Dr. Lewin developed with a visiting colleague from China.

CALIFORNIA SPACE INSTITUTE

THE CALIFORNIA SPACE INSTITUTE, under the direction of Dr. James R. Arnold, administers a universitywide minigrant program that funds researchers in astrophysics, space science, satellite remote sensing, and space technology. These funds, which serve as seed money for program development and student support, are available to all investigators conducting space-related studies in the University of California system.

Cal Space's Earth Remote Sensing Group, led by Dr. Catherine H. Gautier, focuses on the long-term variability of the earth's energy and water cycles and their ecological impact. Group scientists use data from satellite observations to retrieve various geophysical variables of the earth's atmosphere and surface (land and ocean).

Cal Space scientists Drs. Gautier and Robert J. Frouin, in collaboration with others, are preparing for two investigations that will be part of NASA's new Earth Observing System Program. (Several satellites equipped with suites of sensors to monitor the earth will be launched.) In one study scientists will use new sensor capabilities to

compute synoptic ocean-atmosphere exchanges of heat, moisture, and momentum and to examine how the variability of these physical processes govern climate change. In the second project they will develop calibration and retrieval techniques for a new satellite instrument that will observe the earth's atmosphere and surface radiation budget.

Other Cal Space projects include the study of the Indian summer monsoon, work with the Tropical Ocean Global Atmosphere Program, and participation in the International Land Surface Climatology Program. Dr. Geoffrey K. Vallis and Alejandro Pares-Sierra continue to build quasi-geostrophic models of the Pacific Ocean and California Current to test hypotheses of the impact of El Niño events.

Dr. David P. Rogers studies atmosphere-ocean coupling with in situ airborne and surface measurements and numerical modeling. He is studying how cloud fields respond to horizontal variations in sea-surface properties, and the effect of variations in sea surface temperature on energy exchange across the air-sea interface. He



Dr. Lucy-Ann McFadden discusses the physical properties of asteroids.



found a strong diurnal signature in the moisture flux in the marine atmospheric boundary layer caused radiative flux divergence in the atmosphere and variations in the surface forcing. Dr. Rogers's work is elucidating the processes that maintain and dissipate marine clouds.

In addition to their studies of the earth system, Cal Space researchers also investi-

gate the space environment and develop automation and robotic systems for space applications. Philippe Collard uses the ADA programming language to implement on-board systems for NASA's proposed space station. He also develops control architectures for the Flight Telerobotic Servicer, designs parallel computer architectures, and assesses performance with application-

based benchmark programs.

Collard works with the remote sensing group's programming team to construct algorithms to process large-scale, long-term satellite datasets. Working with Dr. Gautier, he develops computer-based procedures to automatically classify cloud types in satellite images. Collard is helping to implement a classification scheme with neural networks that uses the cloud classification output as a training set.

Dr. Lucy-Ann McFadden uses remote sensing techniques to study the physical properties of small solar system objects (asteroids and comets) and their relationships to each other and to meteorites. She completed a study with colleagues comparing the evolution of volatile and dust production of two comets as they approached the sun. This work indicated that comet Wilson, traveling to the inner solar system for the first time, did not have the same rapid fluctuations in volatile and dust abundances as did comet Halley, which had sharply defined active areas at its perihelion passage in 1986. However, the background activity of the two comets, as measured by their relative gas abundances, was the same within a factor of two at similar heliocentric and geocentric distances. Measurements of the fluorescent emission bands of water vapor dissociation products and other volatile species and dust were made at varying heliocentric distances with the International Ultraviolet Explorer, an earth-orbiting ultraviolet telescope.

Dr. Mahmoud Tarokh develops control algorithms for dexterous robot manipulators needed for complex tasks in congested environments. He has developed a digital adaptive control scheme for robots, which is suitable for on-line implementation and is capable of achieving precise trajectory tracking in the presence of robot parameter changes and payloads. A research project on the study of decentralized adaptive controllers for space robots is under way with funding from NASA/JPL. Dr. Tarokh is also studying neural networks for path planning and inverse kinematics of redundant manipulators. Experimental evaluations of this research will use an industrial robot.



INSTITUTE OF GEOPHYSICS AND PLANETARY PHYSICS

THE SAN DIEGO BRANCH of the University of California system-wide Institute of Geophysics and Planetary Physics (IGPP) is located at Scripps and is strongly linked to Scripps through joint faculty appointments, research interests, and shared facilities. Other IGPP branches are located at the Los Angeles and Riverside campuses and at the Los Alamos and Lawrence Livermore national laboratories. Research at IGPP spans numerous fields from seismology to underwater acoustics; in this report two selected programs on very different topics are discussed.

Marine Seismology

Earthquakes, volcanoes, and active geothermal areas are all dramatic manifestations of geodynamic processes on the continents. These phenomena, however, pale in comparison to the extraordinary activity on and under the deep sea floor which occupies 60% of the solid outer skin of the planet. The most seismically active area lies in the deep Tonga-Kermadec Trench, which stretches from northern New Zealand





northward through the Tonga Islands. The mid-ocean ridge system is an active volcanic belt 50,000 km long that circumscribes the earth and is responsible for the genesis of the majority of the earth's outer surface. The East Pacific Rise portion of this ridge, which extends from Baja California, past Chile and Easter Island and toward southern Australia, has the highest rate of volcanism and hydrothermal activity. The tectonic or lithospheric plates on either side of this extensive linear volcano separate under the forces driving sea-floor spreading at rates as high as 120 mm each year. This motion is extraordinary in geological terms; at a rate of 120 mm a year, the generation of the sea floor exceeds the rate of human fingernail growth. The influence of this continuous process on the structure of the outer surface of the planet is substantial. Even the widest ocean basins have been created in about 200 million years, less than 4 percent of the earth's lifetime.

The Marine Seismology Group (Drs. John A. Orcutt, Alistair J. Harding, and Peter Shearer, and graduate students and engineers) has led many studies of the East Pacific Rise. In 1975 IGPP investigators using ocean bottom seismographs found a chamber of molten rock supplying the volcanism on the rise crest. These sophisticated instruments, which have evolved through two generations, are observatory-grade seismographs capable of recording while unattended for months on the rugged sea-floor volcanic terrain. Each instrument can record a gigabyte of digital data—equivalent to more than a million printed pages. The analysis of these data has required the use of super computers. The group has constructed a three dimensional picture of the internal structure of the East Pacific Rise using an approach similar to a CAT scan. The paths that seismic waves take through the rise axis show the outline of a low velocity body, or a region of elevated temperature, when computed from these data. Although similar to medical tomography, the geophysical task is rendered substantially more difficult by the curvature of the seismic wave paths and the paucity and unevenness of the real sea-floor observations.



Dr. Agnew connects the cable to the satellite antenna.

Opposite page: Dr. Duncan C. Agnew adjusts the antenna mount for the new continuously operating satellite geodesy system that monitors crustal motions.



In addition to the exploitation of ocean bottom seismographs, the group collaborated with colleagues at the Lamont-Doherty Geological Observatory, New York, and the University of Rhode Island in applying a seismic technology commonly used in the exploration for petroleum. This approach uses a long, floating streamer containing hundreds of pressure sensors called hydrophones. The internal structure of hundreds of kilometers of the East Pacific Rise along the backbone of the mid-ocean ridge was mapped by a ship from Lamont and one from Scripps. They found that the magma chamber discussed above extends continuously along the axis indicative of the tremendous level of volcanic activity that characterizes the East Pacific Rise.

Research using the seismic tools available at IGPP is not confined to the rise axes. Recently two ocean bottom seismographs were deployed with a remotely operated vehicle. During this experiment, several of these instruments were placed around a Deep Sea Drilling Project borehole in the Atlantic near the Bahamas. The underwater vehicle later placed a string of seismic sensors into the borehole. This and similar experiments are designed to clarify the sea-floor and sub-sea-floor noise environment. They also allow scientists to evaluate the future emplacement of longer-term and even permanent installations for monitoring sea-floor earthquakes and volcanoes, ocean and continental nuclear weapons testing, and to provide warnings of tsunamis or tidal waves.

Space Geodesy

IGPP investigators have begun highly accurate geodetic surveys of crustal deformation. This research has been stimulated by advances in survey techniques that use the Navstar Global Positioning System (GPS) satellites. These satellites, developed by the U.S. Defense Department to provide precise navigation, measure distances to thousands of kilometers with an accuracy of millimeters using highly portable equipment. (Earlier generations of equipment with this precision weighed many tons; a GPS receiver weighs about 45 kg.)

The light weight, long range, and high precision of GPS receivers allow scientists to make precise surveys that could be done in no other way. These are being used to understand how deformation is distributed across the boundary between the Pacific and North American plates in southern California. The earlier measurements, which went only to the coast, left an unknown amount of possible fault motion offshore in the Southern California Borderlands (an area of earthquake activity and recent faulting). One way to study motions in this area is by making precise surveys to the offshore islands, because comparison of these results with earlier ones can give an immediate bound on possible motions. Dr. Duncan C. Agnew is making measurements on San Clemente Island as part of a cooperative project with the Jet Propulsion Laboratory (JPL) and the California Institute of Technology (Caltech). Dr. Agnew and Caltech, MIT, and UCLA investigators formed an informal consortium to make further measurements both onshore and offshore in southern and central California. This consortium has since made over a dozen GPS surveys, including San Clemente, Santa Catalina, and San Nicolas Islands along with observations along the coast from La Jolla to Point Conception.

They recorded the first measurement of crustal shortening in the Santa Barbara Channel; by good luck, a high-precision survey had been done there in 1971. Reoccupation of the same stations in a GPS survey gave a precise measurement of the changes in the last 16 years. In the central channel the main mode of crustal deformation is north-south shortening at about 8 mm/yr; there may also be left-lateral motion in the western channel.

Data gathered in California by the consortium have been analyzed by graduate student Kristine M. Larson, in cooperation with JPL investigators. She has studied both the improvement of GPS analysis procedures and the results of the GPS surveys offshore and onshore. The precision of GPS measurements is usually expressed by their repeatability: the rms scatter of a set of measurements made over several days (the satellites appear once a day). Larson's anal-

ysis of data collected by the consortium shows that the precision of GPS length measurements in a north-south direction is 3 mm plus 10^{-8} of the baseline length. Because of the satellite orbits' arrangement, the east-west accuracy is lower, namely 3 mm and 2×10^{-8} (for a 100-km baseline, the precision is 4 mm north-south and 5 mm east-west). The constant term arises from a combination of receiver error, delays of the signal in the ionosphere and troposphere, and errors in centering the GPS antenna over the survey monument. The length-dependent term comes primarily from errors in the satellite orbits.

The analysis of the data collected in the GPS campaigns in the 32 months since 1986 shows a component of right-lateral strike-slip motion between San Diego and San Clemente Island, with a rate of 10 ± 8 mm/yr. Though these error bars are large, a definite result with this time span is testimony to the high quality of the technique and analysis; data gathered in campaigns in the next two years will do much to improve this. Although GPS measurements across the Santa Barbara Channel only span two years, the north-south compression rate (7 ± 5 mm/yr) is amazingly close to the above result gathered over a longer time. Onshore observations along the central California coastline from Santa Barbara to Monterey show motion consistent with the strike-slip motion of the San Andreas fault.

Future GPS research also will focus on the installation of a network of continuously operating GPS receivers—a project being led by Drs. Yehuda Bock, Agnew, and Jean-Bernard H. Minster and being implemented in cooperation with JPL. With continuously operating fixed receivers, the group hopes to monitor crustal deformation as it happens over hundreds of kilometers. This will open up a new range of spatial and temporal scales. As a first step, GPS receivers will operate at La Jolla (to support a study of sea-level changes) and at the Piñon Flat Observatory (PFO). A high-precision monument has been constructed at Scripps and one will be installed at PFO; these two stations are the first such network in the United States.

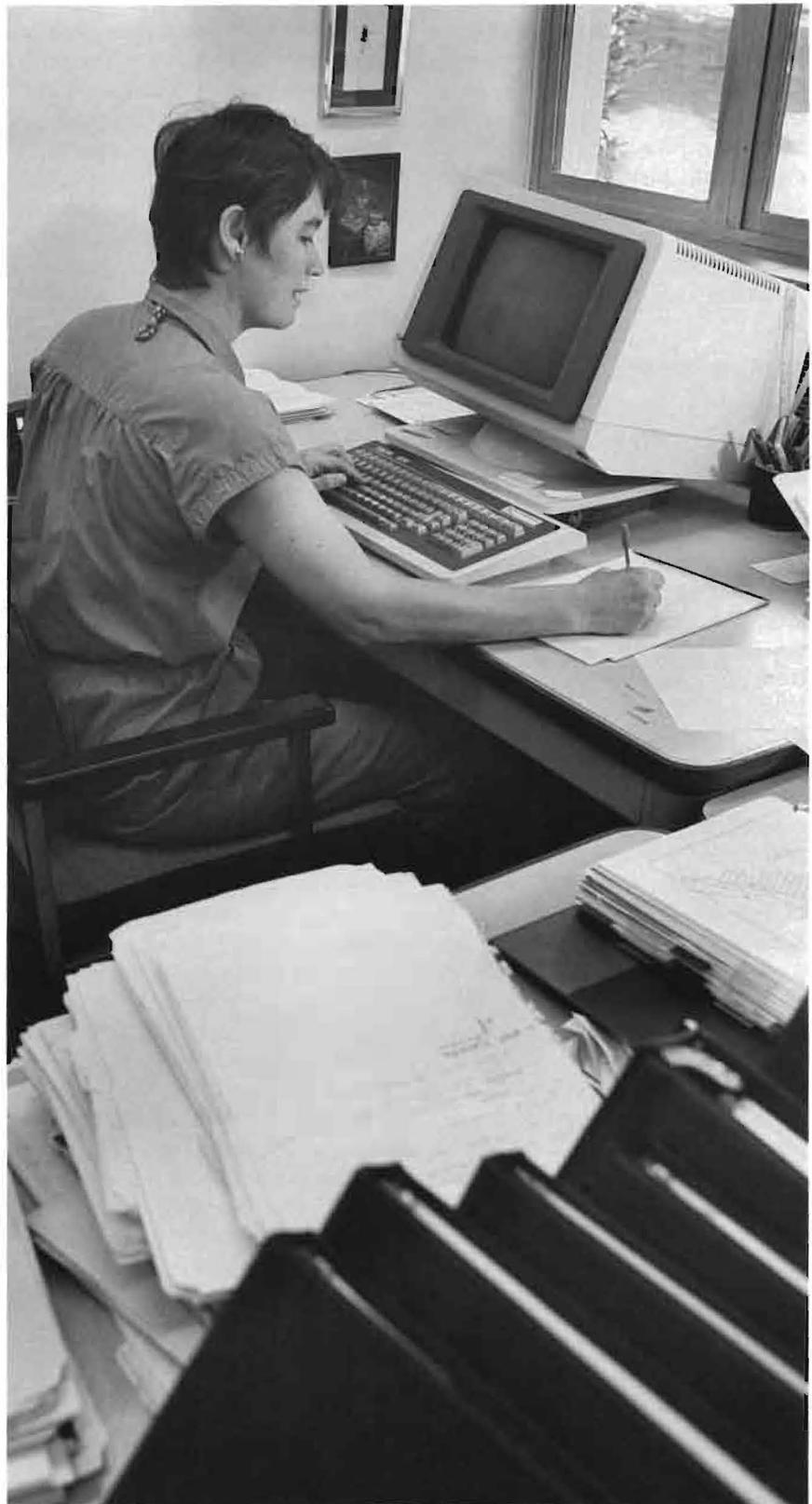


INSTITUTE OF MARINE RESOURCES

THE UNIVERSITYWIDE Institute of Marine Resources (IMR), headquartered at Scripps, supports a variety of research throughout the UC system centered on food chain and ocean engineering programs. With Dr. William H. Fenical as acting director, IMR was major sponsor of an interdisciplinary conference at Santa Barbara: "Values and the American Ocean—Philosophical, Historical, Legal, and Public Policy Perspectives." The conference participants explored the role of government and the rights and duties of citizens toward ocean resources and ocean space. IMR advisory services to the state on water quality, the UC Marine Bio-Optics Group, and ocean circulation studies are highlighted this year.

Water Quality

Under the guidance of Dr. Fenical, the IMR Advisory Committee for the State Water Resources Control Board (SWRCB) evaluated various water quality projects and programs throughout the state as part of a long-term contract with the board. A major review of the California State Board Mussel



Karen S. Baker analyzes physical and biological data collected with bio-optical profiling and moored systems. The data are used to characterize an ocean region and to further develop pigment and production models.



Watch Program was carried out by committee members. Dr. William H. Thomas completed a technical assessment of southern California marine monitoring programs. Drs. Scott A. Jenkins and Jean A. Nichols and David A. Skelly, Scripps Center for Coastal Studies, developed a conceptual model for the fate of suspended solids discharged into the marine environment by public owned treatment works. Detailed reports of these projects are available from IMR.

UC Marine Bio-Optics Group

The University of California Marine Bio-Optics Group (UCMBO) is an IMR inter-campus group directed by Dr. Raymond C. Smith at UC Santa Barbara and Scripps facilities coordinated by Karen S. Baker. The UCMBO group uses experimental work at sea and theoretical modeling to study scientific and applied problems in marine optics. The groups' multidisciplinary research employs ship, buoy, and satellite sampling strategies to study ocean optics and phytoplankton dynamics on a variety of space and time scales. The links between dissolved and suspended material, such as pigment biomass, and the spectral characteristics of optical properties in ocean waters are the focus of their work. They develop bio-optical models that provide a quantitative representation of this link. The group also explores the optical characterization of primary production.

There is a potential for pigment biomass and phytoplankton production to be estimated by satellite, shipboard, and moored optical sensors. While temperature and color satellite imagery give an instantaneous view of the ocean surface, mooring data provide statistics that are continuous on scales of minutes to months, are independent of cloud cover, and provide information as a function of depth. The group is trying to synthesize shipboard and mooring observations with those determined by satellite. Scientists using various sampling strategies will provide more accurate estimates of phytoplankton abundances and population growth rates.

UCMBO researchers have developed and used in-water optical instrumentation

from ships and on untended moorings. This has provided data for many scientists investigating and modeling relationships between physical forcing and subsequent phytoplankton production and optical variability. These shipboard data have also been used in the development and refinement of satellite and mooring ocean color algorithms. Satellite ocean color imagery has been used for the quantitative assessment of both pigment biomass and phytoplankton production. This work has helped give regional and global perspective to the study of carbon fluxes and to the understanding of biogeochemical cycling in the ocean.

Recent UCMBO research included a multidisciplinary program designed to help scientists understand and model the optical variability of the upper mixed layer of the ocean. A deep-sea mooring with a string of physical and optical sensors was deployed in the northern Sargasso Sea (34°N, 70°W). These sensors will record the temporal variability and physical forcings of biological, chemical, and optical processes. The moored optical sensors included downwelling spectral irradiance and upwelling spectral radiance. Wavelengths were chosen to provide both a maximum of biological information and the in-water spectral characteristics that would be sensed by an aircraft and/or satellite ocean color imager. Bio-optical models are currently being used to provide continuous estimates of pigment biomass and phytoplankton production from mooring data.

A second mooring site in the North Atlantic (59.5°N, 21°W) has one of the strongest seasonal changes in mixed layer depth in the world's oceans. Daily observations will provide insight into the seasonal development of this region.

UCMBO scientists are assessing the links between ocean optics and wavelength-dependent productivity of marine phytoplankton. They are building upon a physiologically based bio-optical model that has been used to estimate vertical profiles of instantaneous, diurnal, and integrated daily rates of in situ primary production throughout the water column. The model, based upon an empirical relationship

among photosynthesis, quantum yield, and photosynthetically absorbed radiation, is a full spectral model with all relevant parameters determined as a function of wavelength. They continue incorporating into this model direct measurements of the variability in pigment-specific absorption and photosynthetic action spectra of natural populations of phytoplankton. A "quasi-synoptic" shipboard bio-optical sampling strategy was carried out in California coastal waters. Time-corrected data for several water column populations were obtained on this transect for assessing phytoplankton production in highly variable ocean regions.

Recent attention has been centered on the ultraviolet (UV) radiation reaching the earth's surface and its impact on aquatic environments. The Antarctic is now experiencing a 30–50% springtime loss of its stratospheric ozone layer. This large change may occur over period of only a few days. As a result, interest has been rekindled in earlier research that assessed the impact of enhanced ultraviolet radiation levels on aquatic organisms. The UCMBO group developed a submersible UV-spectroradiometer, determined the optical properties of water in the UV region of the spectrum, showed that UV radiation penetrates to ecologically significant depths in natural waters, and estimated the reduction in phytoplankton productivity caused by increased levels of UV radiation. They are building an updated scanning submersible UV-spectroradiometer to continue this research.

A Bio-Optical Profiling System was designed and developed this year for rapid and simultaneous sampling of spectral irradiance and spectral radiance in addition to other biological, optical, and physical parameters to a depth of 500 m at sea.

Ocean Circulation Studies

Dr. Mizuki Tsuchiya is involved in the Western Equatorial Pacific Ocean Circulation Study (WEPOCS), a joint U.S.-Australian program for the study of circulation and its response to the monsoon variation in the western equatorial Pacific Ocean north and east of Papua New Guinea. In



collaboration with U.S. and Australian scientists, two expeditions were conducted to coincide with the peaks of the southeast trades and the northwest monsoon. Each expedition involved a ship from the U.S. and one from Australia. Several observational components were used in these cruises. Among them were: a grid of conductivity-temperature-depth (CTD) stations with discrete water sampling for oxygen, phosphate, silica, nitrate, nitrite, helium-3, and tritium extending from 143°E to 155°E and from 8°S to 5°N; current-meter moorings in the Vitiaz Strait, St. George's Channel, and the equator at 150°E; full-depth velocity profiling stations from 1°S to 2°N along 150°E; pressure measurements in the Solomon Strait and Vitiaz Strait; and continuous acoustic Doppler current profiler (ADCP) measurements along the cruise tracks.

Special attention was paid to sampling of the western boundary region along the coast of Papua New Guinea and the collection of deep profiles in previously data-poor areas. Scientists focused on determining the source waters of the Equatorial Undercurrent, which starts north of Papua New Guinea and flows eastward along the equator across the Pacific Ocean.

Dr. Tsuchiya is analyzing and interpreting the hydrographic data from these two expeditions. He found that much of the Equatorial Undercurrent water at its beginning north of Papua New Guinea is supplied from the Southern Hemisphere by a narrow western boundary undercurrent. This undercurrent transports high-salinity, low-tritium, high-oxygen, low-nutrient water from the Solomon Sea northwestward along the north coast of Papua New Guinea through the Vitiaz Strait. The ADCP measurements indicate that this boundary current has a maximum speed of 40–70 cm/s at a depth of about 200 m. This current is a permanent feature despite the reversals of the wind and the surface current during the period of the northwest monsoon in austral summer. Current transport through the Vitiaz Strait is estimated to be as high as $8 \times 10^6 \text{ m}^3/\text{s}$, which is of the same order of magnitude as the eastward transport of the Equatorial Undercurrent at 143°E. This sub-

surface equatorward flow has been named the New Guinea Coastal Undercurrent.

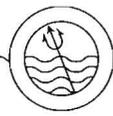
The high-salinity, low-tritium, low-oxygen, high-nutrient water present north of the Solomon Islands flows westward into the Bismarck Sea. It is entrained into the Equatorial undercurrent north of New Ireland and returns to the east, resulting in a downstream increase in the undercurrent transport. Low-salinity, high-tritium, high-nutrient water of eastern North Pacific origin also contributes to the Equatorial Undercurrent at its source west of the WEPOCS region. However, there is no evidence that northern waters are being continuously entrained into the undercurrent in the WEPOCS region.

Dr. Tsuchiya used this same data set to study the flow path of the Antarctic Intermediate Water, which is relatively cold, fresh water that is formed in the Antarctic Convergence and spreads northward at intermediate depths (about 800 m). The most original form of the Antarctic Intermediate Water in the WEPOCS region is in the Solomon Sea and is characterized by low salinity, high oxygen, and low nutrients. It is transported to the equator through the Vitiaz Strait by the New Guinea Coastal Undercurrent.

Part of the intermediate water that crosses the equator north of Papua New Guinea returns to the east in the North Equatorial Countercurrent a few degrees latitude north of the equator. The major portion however, continues northward along the western boundary of the North Pacific, as was shown by previous investigators. Thus, the New Guinea Coastal Undercurrent is important not only as the major source of the Equatorial Undercurrent, but also as the pathway of the Antarctic Intermediate Water from the South Pacific to the North Pacific.

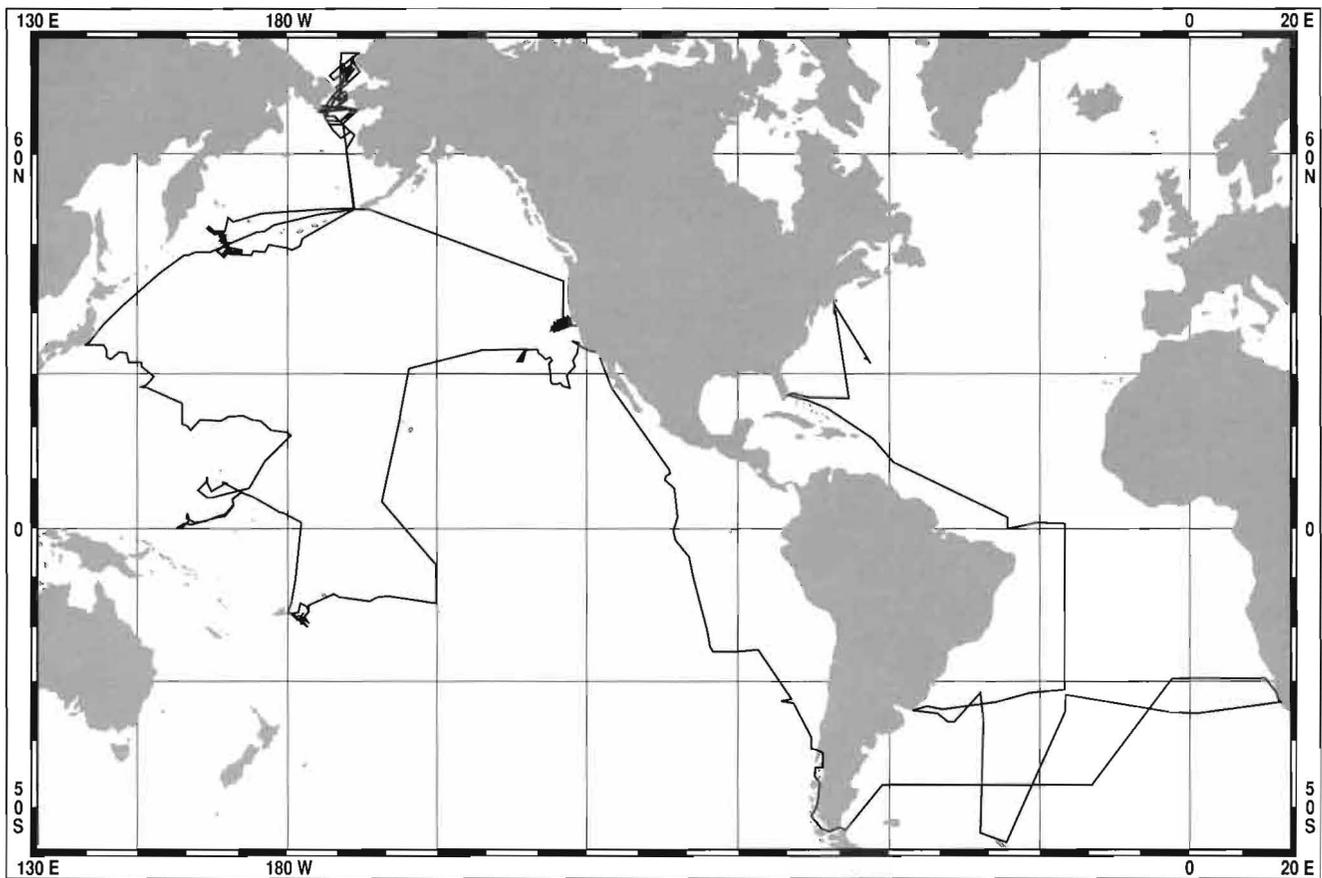


One of the main tools in the study of the ocean is our oceanographic fleet, which is made up of four research vessels and two platforms. Our fleet traveled more than 118,000 nautical miles in fiscal 1988-1989 and operated a total of 977 days. The following charts briefly describe the areas of operations, work performed, and ports of call of this past year's expeditions.



SEAGOING OPERATIONS

SHIP CRUISE TRACKS FOR FISCAL 1989





Research Vessels of Scripps Institution of Oceanography

	<i>MELVILLE</i>	<i>NEW HORIZON</i>	<i>ROBERT GORDON SPROUL</i>	<i>THOMAS WASHINGTON</i>	<i>FLIP</i>	<i>ORB</i>
TYPE	Oceanographic research	Oceanographic research	Offshore supply	Oceanographic research	Floating Instrument Platform	Oceanographic Research Buoy
YEAR BUILT	1969	1978	1981	1965	1962	1968
YEAR ACQUIRED BY SCRIPPS	1969	1978	1984	1965	1962	1968
OWNER	U.S. Navy	University of California	University of California	U.S. Navy	U.S. Navy	U.S. Navy
LENGTH	74.2 m	51.8 m	38.1 m	63.7 m	108.2 m	21.0 m
BEAM	14.0 m	11.0 m	9.8 m	12.0 m	6.0 m	13.7 m
DRAFT	4.9 m	3.7 m	2.5 m	4.4 m	3.4/91.4 m	fwd 1.5 m aft 1.6 m
DISPLACEMENT FULL (metric tons)	1,882	698	513	1,235	1,359	294
CRUISING SPEED (knots)	10	10	9.5	10	varies*	varies*
RANGE (nautical miles)	9,000	6,000	3,500	9,000	varies*	varies*
CREW	23	12	5	23	6	5
SCIENTIFIC PARTY	29–39**	17	12–18**	22	10	10

Fiscal 1988-1989 Total nautical miles traveled: 118,924

Total operating days: 977

*Depends on towing vessel

**With berthing vans



R/V *Melville*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
6/17-7/5/88	Storms	Off Oregon coast	Ocean storms study	Newport	C. Eriksen (UW)	C. Johnson
7/5-7/9/88			Transit	San Diego		C. Johnson
7/18-8/7/88		Santa Barbara Channel	Ocean optics	San Diego	B. Prezelin (UCSB)	C. Johnson
10/10-10/17/88	CIRCUS III	San Diego coast	Instrument positioning	San Diego	F. Spiess	C. Johnson
10/26-11/30/88	HYDROS I	Southeast Pacific, East Pacific Rise	Hydrographic, dredging, and basalt sampling	Punta Arenas	H. Craig	R. Haines
12/7/88-1/15/89	HYDROS II	South Atlantic	South Atlantic Ventilation Experiment	Cape Town	R. Key (Princeton)	C. Johnson
1/23-3/8/89	HYDROS III	South Atlantic	South Atlantic Ventilation Experiment	Montevideo	W. Smithie (LDGO)	C. Johnson
3/13-4/19/89	HYDROS IV	South and North Atlantic	Physical oceanography	Barbados	L. Talley	C. Johnson
4/20-4/26/89			Transit	Miami		R. Haines
5/1-5/23/89	HYDROS V	Off Florida	Borehole re-entry	Woods Hole	F. Spiess	C. Johnson
5/26-6/25/89	HYDROS VI	Off Bermuda	Geochemistry	Woods Hole	P. Williams/ E. Druffel (WHOI)	C. Johnson
6/30-7/10/89	HYDROS VII	Off Florida	Borehole re-entry	Miami	F. Spiess	A. Arsenault

TOTAL DISTANCE TRAVELED: 33,126 nautical miles

OPERATING DAYS: 292

R/V *Thomas Washington*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
6/24-7/23/88	Roundabout IV	Pt. Arenas/ Cape Mendocino	Circulation and biological, chemical, and physical variables	Newport	T. Cowles (OSU)	T. Desjardins
7/27-8/3/88	Roundabout V		Transit	Dutch Harbor		T. Desjardins
8/5-9/5/88	Roundabout VI	Emperor Seamount chain	Geophysical and geological studies	Dutch Harbor	P. Lonsdale/ L. Keigwin (WHOI)	A. Arsenault
9/10-9/29/88	Roundabout VII	North Bering and Chukchi seas	Ecosystem studies	Nome	J. Goering (UA)	T. Desjardins
10/1-10/22/88	Roundabout VIII	North Bering and Chukchi seas	Ecosystem studies	Dutch Harbor	R. Tripp (UW)	T. Desjardins
10/25-11/5/88	Roundabout IX		Transit	Yokosuka		T. Desjardins
11/9-12/13/88	Roundabout X	Western Pacific	Seismic reflection studies	Majuro	E. Winterer	T. Desjardins
12/17-12/31/88	Roundabout XI	Ontong-Java Plateau	Seismic and Sea Beam stratigraphy	Majuro	E. Winterer	A. Arsenault
12/31/88-1/9/89	Roundabout XII	Western Pacific Ocean	Seismic reflection and Sea Beam	Majuro	T. Shipley (UT)	A. Arsenault
1/10-1/19/89	Roundabout XIII	Southwest Pacific	Transit and Sea Beam	Suva		A. Arsenault
1/25-2/1/89	Roundabout XIV	Western Lau Basin	Crustal evolution	Nuku'alofa	J. Hawkins	A. Arsenault
2/2-3/3/89	Roundabout XV	Lau Basin	Sea Beam and dredging	Pago Pago	J. Hawkins	T. Desjardins
3/4-3/20/89	Roundabout XVI		Transit	Honolulu	P. Guenther	T. Desjardins
3/25-4/28/89	Roundabout XVII	Central North Pacific	Organic carbon	Honolulu	K. Smith	T. Desjardins
5/3-5/30/89	Roundabout XVIII	Fieberling Guyot	Sea Beam and Sea Marc II survey	San Diego	P. Lonsdale	A. Arsenault
6/1-8/12/89			Overhaul			

TOTAL DISTANCE TRAVELED: 54,788 nautical miles

OPERATING DAYS: 341



R/V Robert Gordon Sproul

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
7/6-8/5/88		Gulf of California	Shark studies	La Paz	P. Klimley (BBL)	T. Beattie
8/10-8/18/88		Santa Cruz Basin	Tracer studies	San Diego	J. Ledwell (LDGO)	L. Zimm
8/20-8/25/88		Southern California coast	Plankton studies	San Diego	R. Eppley	L. Zimm
8/29-9/1/88		Southern California coast	Equipment launch and recovery	San Diego	W. Hodgkiss	T. Beattie
9/13-9/17/88	ORINCON Leg 1	San Diego Trough	Marine microlayer process studies	San Diego	A. Carlucci	L. Zimm
9/19-9/26/88	ORINCON Leg 2	San Diego Trough	Marine microlayer process studies	San Diego	P. Williams	L. Zimm
10/3-10/8/88		Santa Barbara Channel	Core sampling	San Diego	M. Christiansen	L. Zimm
10/10-10/15/88		Santa Monica Basin	Hydrocasting	San Diego	B. Ward	L. Zimm
11/2-11/3/88		Wilson Cove off San Clemente Island	Install and recover equipment	San Diego	L. Shook (NOSC)	T. Beattie
11/11-11/22/88		Southern California coast	Tracer studies	San Diego	J. Ledwell (LDGO)	L. Zimm
11/28-11/30/88		Santa Barbara Basin	Clam collection	San Diego	C. Cary	L. Zimm
12/14-12/16/88		San Diego Trough	Instrument deployment	San Diego	J. Dufour	T. Beattie
2/22/89		San Diego Trough	Bio-optical instrument testing	San Diego	R. Smith (UCSB)	L. Zimm
2/28-3/2/89		San Diego Trough	Barophilic bacteria collection	San Diego	A. Yayanos	L. Zimm
3/6-3/9/89		Santa Monica Bay	Clam collection	San Diego	H. Felbeck	L. Zimm
3/12/89		San Diego Trough	Demonstration of oceanographic techniques	San Diego	M. Moss	L. Zimm
3/16/89		San Diego Trough	Ocean acoustics	San Diego	W. Hodgkiss	L. Zimm
4/4-4/6/89		Southern California coast	Ocean optics	San Diego	K. Voss	L. Zimm
4/14-4/23/89		Santa Monica and Santa Cruz basins	Tracer release experiment	San Diego	J. Ledwell (LDGO)	L. Zimm
4/25-4/28/89		Southern California	Hydrocast and zooplankton collection	San Diego	D. Lal	L. Zimm
5/13/89		San Diego Trough	Student cruise	San Diego	R. Rosenblatt	L. Zimm
5/22-5/26/89		Santa Monica Bay and Santa Barbara Channel	Animal collection	San Diego	R. Vetter	L. Zimm
5/31/89		Southern California coast	Mocness tows	San Diego	M. Huntley	L. Zimm
6/23-6/25/89		Southern California coast	Tracer experiment	San Diego	D. Lal	L. Zimm
6/27-6/29/89		San Clemente Basin	Barophilic bacteria	San Diego	A. Yayanos	L. Zimm

TOTAL DISTANCE TRAVELED: 9,527 nautical miles

OPERATING DAYS: 123

R/V New Horizon

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
7/9-7/12/88			Transit	Monterey		P. Munsch
7/14-8/2/88		Off Pt. Sur	Benthic flux studies	San Diego	C. Reimers	P. Munsch
8/9-8/24/88		Southern California coast	California Current studies	San Diego	M. Mullin	P. Munsch
8/28-9/22/88		Southern California Bight	Physical oceanography	San Diego	E. Venrick	R. Haines
9/26-10/1/88		Southern California coast	Southern California basins studies	San Diego	R. Jahnke (Skidaway)	P. Munsch
10/1-10/9/88		Southern California coast	Southern California basins studies	San Diego	N. Kachel (UW)	P. Munsch
10/11-10/26/88		Southern California coast	California Current studies	San Diego	M. Mullin	P. Munsch
10/29-11/23/88		Southern California coast	Electromagnetic sounding studies	San Diego	C. Cox	P. Munsch
11/29-12/5/88		Catalina Basin	Pelagic animal and organic transport studies	San Diego	K. Smith	P. Munsch
12/12-12/15/88		Southern California Bight	Instrument deployment and recovery	San Diego	W. Hodgkiss	P. Munsch
4/16-4/30/89		Southern California Bight	Amino acid cycling	San Diego	J. Fuhrman (USC)	P. Munsch
5/19/89		Southern California Bight	Equipment testing	San Diego	T. Chereskin	P. Munsch
5/23/89		Southern California Bight	Sound source system test	San Diego	F. Fisher	P. Munsch
5/30-6/5/89		Southern California Bight	Engineering tests of RUM III	San Diego	V. Anderson	P. Munsch
6/14-6/30/89		Southern California Bight	Benthic biology	San Diego	K. Smith	P. Munsch

TOTAL DISTANCE TRAVELED: 20,066 nautical miles

OPERATING DAYS: 169



R/P ORB

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	*CAPTAIN
9/16/88		32°-53°N, 117°-23°W	Thruster system tests	San Diego	V. Anderson	T. Hoopes
9/20/88		Off San Diego	Thruster system tests	San Diego	V. Anderson	T. Hoopes

TOTAL DISTANCE TOWED: 27 nautical miles

OPERATING DAYS: 2

*OFFICER-IN-CHARGE OF FLOATING PLATFORM

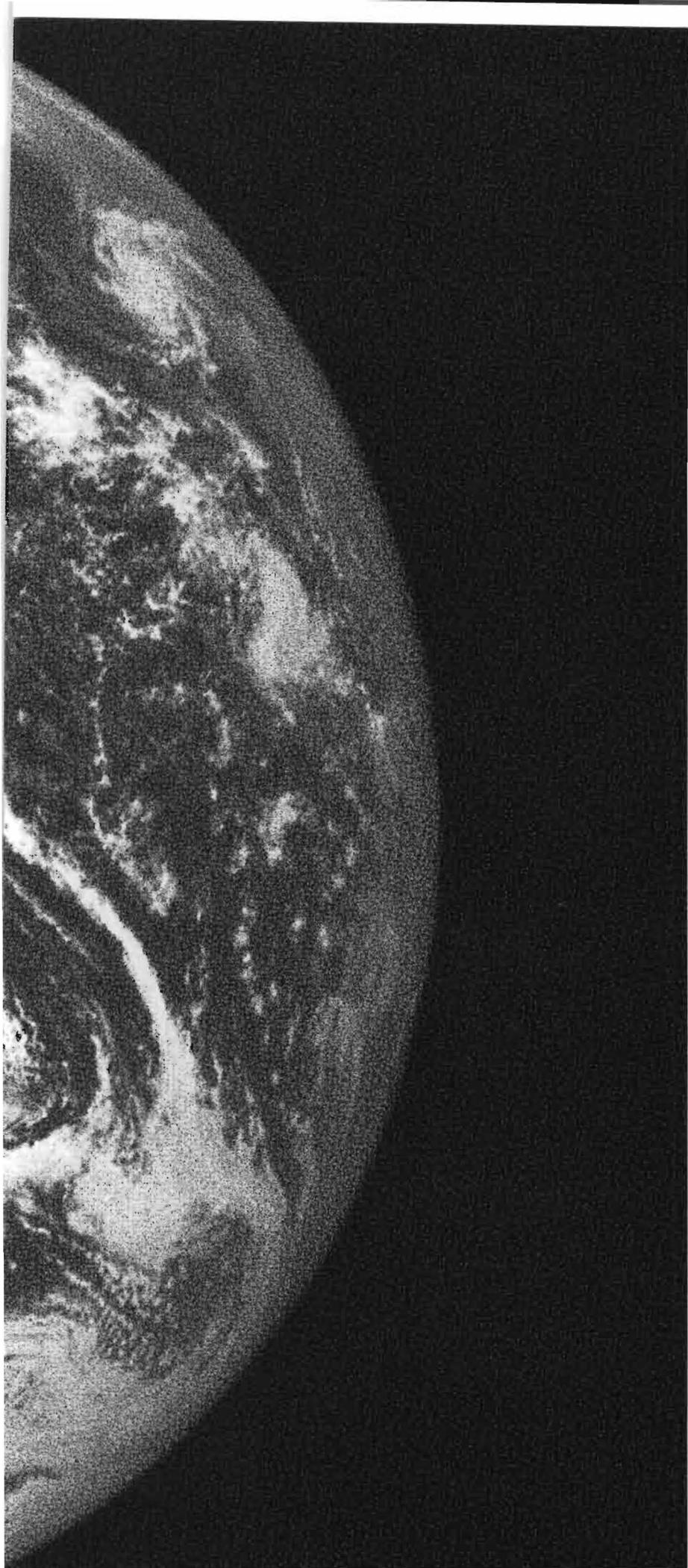
R/P FLIP

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	*CAPTAIN
9/28-10/1/88		San Diego		San Diego	D. Leonard	D. Effird
11/4-11/15/88		San Diego		San Diego	R. Pinkel	D. Effird
2/2-2/13/89		San Diego		San Diego	J. Hildebrand	D. Effird
5/11-5/19/89		32°-37°N, 120°-32.9°W	Array tests	San Diego	J. Hildebrand	D. Effird
6/20-7/21/89		34°N, 140°W	Array tests	San Diego	J. Hildebrand	D. Effird

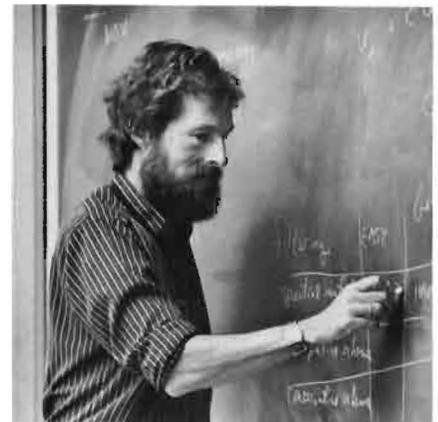
TOTAL DISTANCE TOWED: 1,390 nautical miles

OPERATING DAYS: 50

*OFFICER-IN-CHARGE OF FLOATING PLATFORM



*Dr. Richard C. J. Somerville
teaching his numerical fluid
dynamics class.*



In the fall of 1988, 23 new students were admitted to graduate study. Of these, 6 were in marine biology, 2 in geological sciences, 1 in geochemistry and marine chemistry, 1 in geophysics, 4 in physical oceanography, 3 in applied ocean sciences, and 6 in biological oceanography. Enrollment at the beginning of the academic year was 189.

UC San Diego awarded 20 Doctor of Philosophy degrees and 5 Master of Science degrees to the students listed on page 49 of this report.



GRADUATE DEPARTMENT

THE GRADUATE DEPARTMENT OF THE SCRIPPS INSTITUTION OF OCEANOGRAPHY offers instruction leading to Ph.D. degrees in oceanography, marine biology, and earth sciences. Because of the interdisciplinary nature of the ocean sciences, the department provides a choice of seven curricular programs through which the student may pursue a five-year Ph.D. degree. Each of these curricular groups has prerequisites for admission in addition to the departmental requirements. The curricular programs are described below. For application procedures and more information, please write to Graduate Department, A-008, Scripps Institution of Oceanography, La Jolla, California 92093.

Applied Ocean Sciences

This interdepartmental curriculum combines the resources of the Scripps Graduate Department with those of the Department of Applied Mechanics and Engineering Sciences and the Department of Electrical and Computer Engineering, on the UC San Diego campus. Engineers gain a substantial education in oceanography, and oceanographers receive training in modern engineering. Instruction and basic research include the applied science of the sea, and structural, mechanical, material, electrical, and physiological problems within the ocean.

Biological Oceanography

Biological oceanographers study the interactions of marine organisms with the physical-chemical environment and with each other. Research and instruction in this curriculum range from food-chain dynamics and community structure to taxonomy, behavior, physiology, and zoogeography.



Students attending their numerical fluid dynamics class.



Geochemistry and Marine Chemistry

The geochemistry and marine chemistry curriculum emphasizes the chemical and geochemical processes operating in the oceans, the solid earth, the atmosphere, marine organisms, polar ice sheets, lakes, meteorites, and the solar system. This program, designed for students with undergraduate majors in either chemistry or geology, features areas of advanced study and research that include the physical and inorganic chemistry of seawater; ocean circulation and mixing based on chemical and isotopic tracers; marine organic and natural products chemistry; geochemical interactions of sediments with seawater and interstitial waters; geochemistries of volcanic and geothermal phenomena; chemical exchanges between the ocean and the atmosphere; geochemical cycles of carbon, sulfur, nitrogen, and other elements; isotope geochemistry of the solid earth and meteorites; atmospheric trace gas chemistry; paleoatmospheric composition recorded in polar ice cores and in sediments; and chemistry of lakes and other freshwater systems.

Geological Sciences

This curriculum applies observational, experimental, and theoretical methods to the understanding of the solid earth and solar system and how they relate to the ocean and atmosphere. Principal subprograms are marine geology and tectonics, sedimentology, micropaleontology and paleoceanography, petrology and geochemistry. Expedition work at sea, and field work on land are emphasized as essential complements to laboratory and theoretical studies.

Geophysics

This curriculum is designed to educate the physicist (theoretician or experimentalist) about the sea, the solid earth on which the waters move, and the atmosphere with which the sea interacts. Students gain understanding of the nature of the earth while they master new field, laboratory, and mathematical techniques.

Marine Biology

The marine biology curriculum emphasizes the biology of marine organisms—animals, plants, and prokaryotes. The research and teaching encompass a range of biological disciplines, including behavior, neurobiology, developmental biology, and comparative physiology/biochemistry.

Physical Oceanography

Studies in physical oceanography include observation, analysis, and theoretical interpretation of the general circulation of ocean currents and the transport of dissolved and suspended substances and heat; the distribution and variation of oceanic properties; the propagation of sound and electromagnetic energy in the ocean; and the properties and propagation of ocean waves.



GRADUATE STUDENTS AND DEGREE RECIPIENTS

Doctor of Philosophy Degrees Awarded, with Titles of Dissertations

Earth Sciences

Andres J. Mendez, "Forward Modeling and Inversion of Near-Source Earthquake Ground Motion."

Glenn Sasagawa, "Instrument Validation and Application of an Absolute Gravity Meter in Long Valley and California."

Mark F. Smith, "Imaging the Earth's Aspherical Structure with Free Oscillation Frequency and Attenuation Measurements."

Kenneth M. Toy, "Tomographic Analyses of ISC Travel Time Data for Earth Structure."

Frank L. Vernon III, "Analysis of Data Recorded on the ANZA Seismic Network."

Jill M. Whitman, "Stable Isotope Record of Foraminifera from Ontong Java Plateau for the Last 6 Million Years, DSDP Site 586."

Marine Biology

Byung C. Cho, "Significance of Bacteria in Biogeochemical Fluxes in the Pelagic Ocean."

Oceanography

Beth Chertock, "Global Monitoring of Net Solar Irradiance at the Ocean Surface Using Nimbus-7 Satellite Data."

Giulietta S. Fargion, "Physical and Biological Patterns During El Niño and Non-El Niño Episodes in the California Current."

David C. Jacobs, "Observations of Vertical Shear and Reynolds Stresses in the Main Thermocline of the Deep Ocean and Measurements of the Near-Field Microseism Pressure Spectrum."

Clifford H. Keller II, "A Sensory-Motor Interface in Weakly Electric Gymnotiform Fishes."

Teresa L. Klinger, "Maintenance of the Biphasic Life History in Isomorphic Brown Algae."

Denise C. Manker, "Occurrence, Origin and Function of Secondary Metabolites in Marine Pulmonate Molluscs."

Patricia A. Matrai, "Phytoplankton Production of Organic Sulfur in the Ocean Surface Waters."

Mark A. Merrifield, "Shelf Circulation in the Gulf of California."

James K. Orzech, "Marine Snow as an Emitter of Light in the Sea."

Uwe Send, "Heat and Flow Response to Upwelling Relaxations."

Jeffrey T. Sherman, "Observations of Fine-Scale Vertical Shear and Strain in the Upper Ocean."

Jan Svejksky, "Monitoring of High-Frequency Ocean Variability from Satellite-Borne Sensors and its Application to the Study of Distributions of Albacore Tuna (*Thunnus alalunga*)."

Mark J. Warner, "Chlorofluoromethanes F-11 and F-12: Their Solubilities in Water and Seawater and Studies of Their Distributions in the South Atlantic and North Pacific Oceans."

Master of Science Degrees

Marine Biology

Michele K. Nishiguchi

Oceanography

Saima Aijaz

Sabine E. Apitz

John M. Dimento

Andrew J. Magenheim

Walter Nordhausen

Angel M. Rodriguez

Ruth Simon



*Scripps Institution of
Oceanography Library.*



*The numerous facilities and
collections at Scripps are used
both for teaching and re-
search. Several of these are
also available to those out-
side the Scripps community
either for a fee or for free.*

*Each facility and collection is
described briefly in this sec-
tion. For more information
please write directly to the
specified facility or collection
in care of Scripps Institution
of Oceanography, La Jolla,
California 92093.*

*Each year one of these facili-
ties or collections is described
in photos. This year the
Scripps Library is featured
throughout this section.*



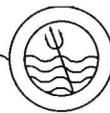
FACILITIES AND COLLECTIONS

SHORE FACILITIES

Analytical Facility

Instruments at the facility include a Philips automated x-ray fluorescence spectrometer with computerized control and data analysis; three x-ray diffraction systems, including a Philips APD 3600/02 with computer-aided search/match mineral files; a Perkin Elmer Zeeman/5000 atomic absorption/fluorescence spectrometer with heated graphite, furnace auto sampler, and metal hydride systems; a Hewlett-Packard 5988 computerized GC/mass spectrometer and four H/P gas chromatographs with EC, FI detectors; a Perkin Elmer HPLC with multicolumn capability and fluorescence; diode array detectors; a superconducting IBM nuclear magnetic resonance spectrometer with an aspect 3000 color graphic system; a Coulometrics total carbon/CO₂ analyzer; a P/E model 2400 CHN analyzer; a P/E radio-recording computerized infrared spectrometer; a P/E UV-VIS Lambda 3B spectrometer; a Cambridge 360 scanning electron microscope with a Link energy-dispersive x-ray spectrometer and image analysis system; a Hitachi H-500 scanning transmission electron microscope with an Ortec EDS x-ray spectrometer; a Zeiss 9 TEM; diamond knife microtomes; a Cameca "Camebax" electron microprobe with three automated crystal spectrometers, polarized light optics, SEM, TEM capabilities, Ortec EDS x-ray system, and a Canberra/DEC computer system.

The Analytical Facility also has several complete sample preparation laboratories, including "wet" chemical, rock processing, biological EM, photographic, vacuum evaporation/sputtering, sedimentation, and grinding/lapping.



Mary E. Jackson-Evans checking in periodicals on computer.



Aquarium Facilities

There are two research aquarium facilities; each is provided with a dual-line system that delivers seawater at ambient temperatures. The Experimental Aquarium (250 m²) is equipped with 5 rooms for controlled experiments, 20 tanks with capacities from 425 to 2,200 liters, 9 seawater trays, counter space, sinks, and lockers. A single-line chilled seawater system delivers approximately 150 liters per minute at 10°C. The Marine Biology Aquarium (280 m²) is equipped with 26 tanks with capacities from 750 to 1,500 liters, 16 seawater trays, counter space, and sinks. Two chilled seawater systems deliver approximately 300 liters per minute at temperatures of approximately 2°C and 8°C, respectively.

Cardiovascular Research Facility

This facility, shared by the Physiological Research Laboratory and the UC San Diego School of Medicine, consists of an experimental animal colony; equipment for measuring circulatory and cardiac functions in

conscious, unrestrained animals; and an instrumentation development laboratory.

Diving Facility

The research diving program is housed in two separate facilities that contain the mechanical gear, a storage locker for wet equipment, and showers.

The scientific diver training and certification program, which originated at Scripps in 1951, is the oldest of its type in the country. The program consists of a non-recreational 100-hour training class in the use of open-circuit scuba, which may lead to University of California research diver certification. This class is open to faculty, staff, and students who must conduct underwater research. Each year an average of 130 Scripps/UC San Diego personnel participate in the scientific diving program. These individuals conduct their research in waters throughout the world, including the Antarctic.

Electromechanical Cable Test Facility

Located at Marine Physical Laboratory, Point Loma, this special-purpose facility enables scientists to investigate the physical properties of electromechanical cables used in deep-sea research operations and to develop new methods of splicing and repair.

Ellen Browning Scripps Memorial Pier

The 320-m pier serves as a launching site for small boats used for local oceanographic work, provides space for studies and tide gage and weather recordings, and supports the seawater system that supplies the aquaria and laboratories.

The original pier was constructed in 1916 with funds provided by Ellen Browning Scripps. The new pier, which was dedicated in 1987, is 2 m wider and 15 m longer than the original pier. It is located immediately to the south of the former structure and provides increased seawater flow for the support systems at Scripps as well as improved boat launching and sampling facilities.

Hydraulics Laboratory

This laboratory has a wind-wave channel 43 x 2.4 x 2.4 m, with a tow cart for instruments and models; a two-layer flow channel, test section 1.1 x 1.1 x 16 m; a 15 x 18-m wave-and-tidal basin with an adjustable, simulated beach; a 40-m, glass-walled, wave-and-current channel; a granular fluid mechanics test facility comprising a 6 x 12 x 3-m concrete basin, a 10 x 1 x 1-m fluidizing channel, and three tanks 4 m high by 5 m in diameter, all serviced with a high-flow, slurry pumping system; a 16-m oscillatory flow tunnel; an insulated, refrigerated, cylindrical, seawater tank 10 m deep and 3 m in diameter equipped with artificial lighting; a pressure facility 2 m long with a 57-cm interior diameter; and a temperature and pressure calibration facility. All wave generators in the laboratory incorporate servo systems and can be controlled by computer or magnetic tape. Microcomputer-based data acquisition and data process-



ing systems are used in conjunction with the various facilities.

Kendall-Frost Mission Bay Marsh Reserve (Mission Bay, San Diego)

Approximately 50 acres of Mission Bay marshland (16 acres university-owned) constitute a marsh preserve and wildlife refuge designated for teaching and research. The reserve is the last fragment of the once extensive Mission Bay salt marsh. This property is one of 27 natural reserves used for teaching and research in the University of California Natural Reserve System. A small laboratory is located on the preserve. For more information write to the Reserve Manager, UC San Diego Natural Reserve System, Scripps Institution of Oceanography, A-001, La Jolla, California 92093.

Marine Science Development and Outfitting Shop

This shop is equipped with precision tools and machinery. A staff of toolmakers and diemakers designs and fabricates research equipment and instrumentation for various Scripps laboratories and other educational and governmental organizations throughout the United States.

Mass Spectrographic Equipment

Ten mass spectrometers are available: two 15-cm, Nier-type spectrometers and one 6-cm Micromass instrument for isotopic analysis of light elements; a 15-cm, Nier-type spectrometer for rare gases; a 25.4-cm double-collection mass spectrometer for He^3/He^4 ratio measurements; a Hewlett-Packard 5988 gas chromatograph-quadrupole mass spectrometer for qualitative separation and analysis of organic compounds; a 30-cm-radius, solid-source mass spectrometer for geochronology and isotope dilution analysis; a small, portable, helium mass spectrometer for field use; a Finnigan stable isotope mass spectrometer for the analysis of gases; and a 3-cm mass spectrometer for stable isotope tracer measurements.



Paul M. Leverenz applies a chart correction to a nautical chart. There are currently more than 63,000 items in the Scripps Library Map and Chart Collection.

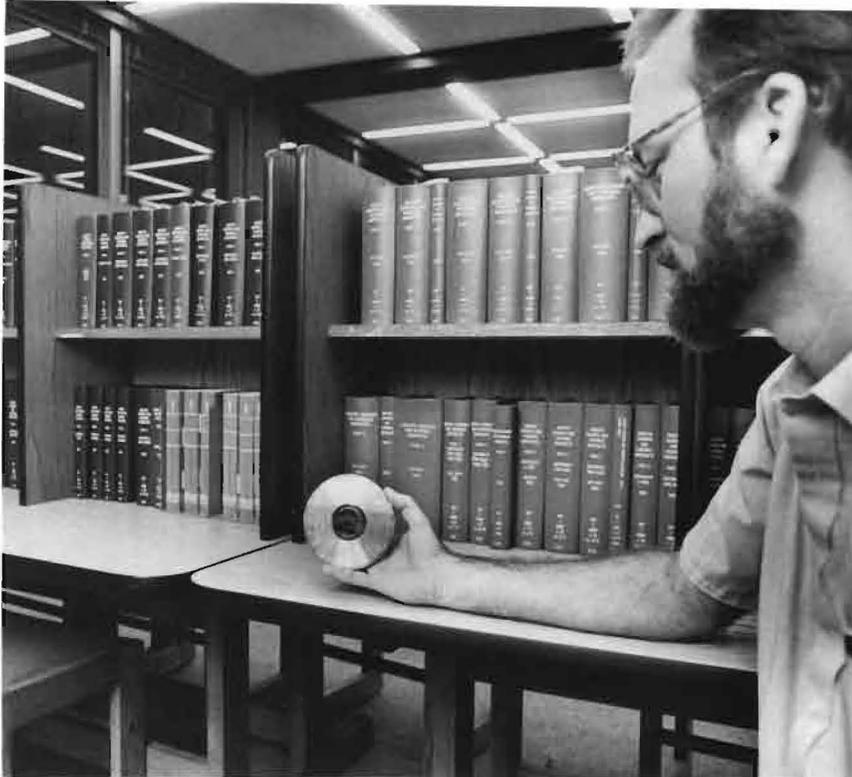
Petrological Laboratory

This facility provides thin-sectioning, microprobe sample preparation, and rock-surfacing services to staff, students, and associated research groups. All types of

submarine and subaerial igneous, metamorphic, and sedimentary materials in various states of lithification are prepared here with plastic-vacuum techniques and other types of impregnations.



The compact disk held by Peter L. Brueggeman is a database equivalent to all the volumes in the background.



Physiological Research Laboratory Pool Facility

This facility includes a holding pool for large marine mammals and fish, and a ring pool with a 10-m radius equipped with a variable-speed trolley to carry instruments for hydrodynamic and biological studies of humans and other mammals. A central island within the ring pool contains small, "dry" laboratories and a "wet" laboratory equipped to handle large animals. A channel through the island permits transfer of animals from the ring pool into the laboratory.

Radio Station WWD

Owned and operated by Scripps and licensed to the National Marine Fisheries Service (NMFS), station WWD provides worldwide communications services to Scripps, NMFS, and other governmental and university ships. Western Union (TWX-Telex), TELEFAX, and Telemail services are available for the San Diego campus. WWD has computerized its radio and TWX-Telex for local users.

San Vicente Lake Calibration Facility (48 km from Scripps)

This facility, operated by the Marine Physical Laboratory, is equipped for testing and calibrating acoustic transducers used in oceanographic research. The equipment is located on an 8 x 15-m enclosed platform in water 40 m deep, and offers an unobstructed range of 1,372 m.

Scripps Coastal Reserve

The reserve area is situated just north of La Jolla, where a small hooked bay opens to the northwest. The shelf area within the bay is cut by two branches of the Scripps submarine canyon, extending to within 300 m of the low-tide shoreline.

This area is collectively called the Knoll and consists of two coastal canyons, the knoll between the canyons, and 106-m-high, steep sea cliffs. Numerous archaeological sites are located in this region.

The shoreline area consists of intertidal rocky and beach environments; the under-

water area contains various subtidal marine habitats including the canyon and a 320-m pier. The area is adjacent to the San Diego-La Jolla Ecological Reserve of the California Department of Fish and Game.

Scripps Library

With outstanding collections in oceanography, marine biology, and marine technology, in addition to extensive resources in atmospheric sciences, ecology, fisheries, geology, geophysics, and zoology, the Scripps library is the largest marine science library in the world. The library currently receives more than 3,700 serial titles and has more than 210,000 volumes, including an extensive collection of technical reports and translations, and a rare book collection featuring accounts and journals of famous voyages of scientific discovery. A large map collection contains bathymetric, geologic, and topographic maps and charts of world areas and oceans.

The library also houses the archives of the Scripps Institution of Oceanography, which include official Scripps records, personal papers, photographs, and other material documenting the history of oceanography and of Scripps.

Scripps Satellite Oceanography Facility

This facility enables oceanographers to receive and process satellite imagery. Data transmitted in real time by the NOAA polar orbiting satellites are received by the 5-m tracking antenna and stored on computer-compatible tapes. In addition to real-time coverage, retrospective archives of worldwide data are also available. The most commonly used sensors include the Advanced Very High Resolution Radiometer (AVHRR) and Coastal Zone Color Scanner (CZCS), which provide information in the infrared and visible portions of the spectrum. Scanning Multichannel Microwave Radiometer (SMMR) data, from which sea-surface winds may be derived, are also processed at the facility.

The central processor is an HP 3000 Series II computer dedicated to the facility. This processor has 2 megabytes of main



memory and 250 megabytes of disk storage. Tape drives capable of operating at 800, 1,600, or 6,250 bpi densities assure complete versatility. A high-resolution color display station allows users full interaction with the satellite imagery at near-real-time rates for most common operations. This particular hardware configuration is presently being replaced with a DEC Micro VAX II system that will handle data collection and archiving and a HP 9000 Series computer that will handle data processing and analysis. Both systems will be significantly faster and have more storage capabilities. Current applications include tracking of drifting buoys via the ARGOS data collection system, and near-real-time support of research vessels and aircraft by using remote detection to determine sea-surface temperature. It is anticipated that GEOSAT altimeter data also will be processed on the new systems. Once the hardware update is complete, a four-day course will be taught every quarter by the facility staff to give potential users an overview of the available tools as well as several hours of hands-on experience.

Seawater System

Pumps located on the seaward end of Ellen Browning Scripps Memorial Pier deliver seawater to the laboratories and aquaria of Scripps and the National Marine Fisheries Service. The raw seawater is filtered through three, 18-cm-diameter, high-speed sand filters and pumped up into two concrete storage tanks with a total capacity of approximately 450,000 liters. Water flows by gravity to the public aquarium and Scripps research laboratories, while approximately 750 liters per minute are pumped up to the National Marine Fisheries building. The system is capable of delivering a maximum of 7,200 liters per minute.

Shipboard Technical Support

Shipboard Technical Support is an amalgamation of several groups that serve both Scripps and the oceanographic community at large. The group provides technical and



Archivist Deborah C. Day examines manuscript material on the history of oceanography.



data-collection services aboard Scripps's research vessels, supplying and maintaining shipboard scientific facilities (computers and geological, biological, physical, and chemical data-acquisition systems); logistic support for these facilities; and postcruise data processing, distribution, and archiving. Shipboard Technical Support also furnishes data collection equipment and highly trained technicians for University National Oceanographic Laboratory System (UNOLS) ships and international programs.

The ship support administrative organization comprises the Shipboard Computer Group, resident technicians, geophysical technicians, the Geological Data Center, and the Oceanographic Data Facility. For administrative purposes, the Scripps scientific collections and the Geological Data Center are part of Shipboard Technical Support; for further information about them see the Special Collections section.

The **Shipboard Computer Group** is composed of programmers and engineers who support VAX/UNIX computers ashore and at sea through programing, interface design, and maintenance. A shore-based VAX 750, available for use by the Scripps community, supports the VAX 730s on the ships. These computers are installed permanently on *R/V Thomas Washington* and *R/V Melville*; and they are interfaced to navigational and scientific instruments, including the *R/V Thomas Washington* Sea Beam system.

Resident technicians are knowledgeable guides who dive, rig, handle explosives, operate geological sampling gear, operate net tows and trawls, and perform a wide variety of other tasks on Scripps research vessels. They also handle logistics for expeditions, and receive and store scientific equipment for future cruises.

Geophysical technicians provide and operate the analog and digital seismic reflection systems using airguns or waterguns and refraction systems. They maintain the magnetometers and echo-sounding systems installed on Scripps vessels.

Technicians in the **Oceanographic Data Facility (ODF)** collect data and samples for investigators from Scripps and other institutions. ODF also maintains an inventory of water samplers and other equipment, avail-

able at cost to qualified users. More sophisticated or expensive apparatus may be used only when accompanied by ODF technicians, who operate and maintain the equipment at sea.

The group participates in expeditions by making high-precision hydrographic measurements, specializing in Neil Brown Instrument Systems CTD (conductivity, temperature, depth) work, and shipboard determinations of salinity, dissolved oxygen, nutrients (silicate, phosphate, nitrate, and nitrite), alkalinity, and total CO₂ from water samples collected with multiple-bottle samplers.

ODF resources include a chemistry laboratory; an electronics shop; a CTD and deep-sea, reversing-thermometer calibration laboratory; and a data processing and computer facility. The processing equipment includes a HP 1000 minicomputer as a shore-based processor, and seven Tektronix 4050 series microprocessors used primarily at sea to monitor CTD data acquisition.

Shipboard equipment for acquiring and processing data has been substantially improved. CTD instruments have been rebuilt, and the IBM-based data acquisition system (which served to develop the UNIX-based software) has evolved into an Integrated Solutions Inc. microcomputer-based system. These processors have proved to be rugged and reliable for shipboard use. The group has also acquired two HP integrated computers for seagoing data processing where no CTD casts are taken.

SSURF: SIO Supercomputer Users Remote Facility

The SSURF computer center provides computer services for the Scripps community. A high-speed data connection to the San Diego Supercomputer Center is just one part of SSURF's function. Electronic mail can be sent on ARPAnet, BITnet, NSFnet, OMNet, and SPAN to other computers worldwide. SSURF also has data processing utilities including numerous statistical and plotting software packages, and over seven different computer programing languages. Consultants also provide assis-

tance on software, hardware, electronic mail, intercomputer data transfer, networking, and supercomputer usage.

SSURF is a VAX 11/785 computer running both VMS and UNIX operating systems. Connected to SSURF is an array of plotters, printers, tapedrives, and over 2000 megabytes of disk storage. The SSURF computer center services are available 24 hours a day year-round.

Thomas Wayland Vaughan Aquarium-Museum

The aquarium-museum is the interpretive center for Scripps Institution of Oceanography. Its goals are to increase public understanding and appreciation of the oceans and to generate support for marine research. The facility features museum exhibits on oceanographic topics, a variety of educational programs, and displays of living marine animals from local waters and the tropical Pacific. This year more than 50,000 students in educational groups participated in study trips to the aquarium-museum. The aquarium is open to the public daily; admission is by donation: \$3.00 is requested from adults, \$2.00 from children 12-18 and senior citizens.

Aquarium-museum staff offers UC San Diego and Scripps researchers aid and information on marine organism maintenance, fish diseases, local species distributions, and other related topics. Through its collecting facility, the aquarium supplies scientists with living specimens.

A new aquarium-museum, to be named the Stephen Birch Aquarium-Museum in honor of the major donor, has been designed and is scheduled for completion in December 1991. The new facility will be 3 times larger than the present one. The project is expected to cost approximately \$8.6 million, exclusive of parking and roads.

Scripps Aquarium Associates, the aquarium-museum public membership group, offers ocean-related activities to its members, including local field trips, lectures, family activities, scuba and snorkeling expeditions, a calendar, and a newsletter.



SPECIAL COLLECTIONS

Benthic Invertebrates

The collection contains some 33,000 lots of specimens sorted into major taxonomic groups such as Coelenterata, Echinodermata, Crustacea, and Mollusca. All are accessioned with collection data, and more than 35 percent are identified to species. Specimens, several catalogs of holdings (Decapod and Stomatopod Crustacea, Brachiopoda, and Echinodermata), and IBM-compatible dBase IV catalog data for various groups are available to qualified students and researchers.

Geological Core Locker

This geological "library" contains a collection of several thousand deep-sea sediment cores kept under refrigeration, and bulk assemblages of rocks and manganese nodules dredged from the major ocean basins. These materials are available to scientific investigators and students.

Geological Data Center

The Geological Data Center provides at-sea data processing and on-shore process-

ing, distribution, and archiving of under-way marine geophysical data. Navigation, depth, magnetics, gravity, and Sea Beam data are computer-processed for entry into the digital database and for production of cruise reports and plots. A multidisciplinary index of all samples and measurements made on major Scripps cruises is maintained by the data center. Charts and other geophysical data sets are also available.

Marine Botany Collection

A small herbarium of marine benthic algae incorporates specimens from the U.S. Pacific coast, chiefly from the San Diego area, or collected during Scripps expeditions in the Pacific Ocean. There are some 1,600 sheets of pressed seaweeds, identified and arranged in taxonomic order. The specimens, although primarily used for teaching, are available for examination by any botanist or interested student.

Marine Invertebrates

Included in this collection of more than 53,000 documented whole zooplankton samples are accessioned holdings from expeditions, the continuous CalCOFI program, and special projects. Samples represent zooplankton collected with nets, ranging from surface neuston to bathypelagic midwater trawls. The major emphasis of the collection has been in the northeastern Pacific, but an increasing number of samples are also available from other oceanic and continental slope regions. The collection includes identified specimens for some of the major taxonomic groups. Samples are supplemented with physical and chemical data.

Marine Vertebrates

This collection contains approximately 2.5 million specimens, with over 4,000 cataloged species, including 160 primary types. Approximately 200 collections are added each year. Although the collection is worldwide, deep-sea fishes and eastern Pacific shorefishes are emphasized. Included are large holdings of shorefishes from the Gulf

of California and Panama, and an extensive skeletal collection of dried preparations and cleared-and-stained specimens in glycerin with over 700 species represented. The otolith collection contains otoliths from 459 species.

Oceanographic Data Archives

Tide-gage records have been taken daily from the Scripps Pier since 1925. Monthly tide-gage records from 1947 to 1967 and from 1980 to the present are available in the Scripps Library archives. Records before 1947 and from 1967 to 1980 can be obtained by writing the Chief of the Datums and Information Branch, C-233, NOAA/NOS, 6011 Executive Blvd., Rockville, MD 20852.

Data from more than 20,000 hydrographic casts from Scripps cruises are managed by Shipboard Technical Support. The Marine Life Research Group manages an additional 45,000 stations of hydrographic data as well as daily temperature and salinity records from data collected at Scripps Pier and other shore stations along the California coast.

Historical meteorological and oceanographic data for the Pacific are kept in the NORPAX data library. These data include marine weather and sea-surface temperature observations from 1854 to the present; National Oceanographic Data Center files to 1976; and monthly pressure, temperature, and precipitation at selected World Meteorological Organization stations.

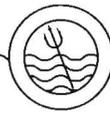
Scripps Core Repository of the Ocean Drilling Program

The Scripps core repository (under lease agreement with the Ocean Drilling Program at Texas A & M University) houses the West Coast repository for cores collected by the Deep Sea Drilling Project in the Pacific and Indian oceans. Core samples are made available to qualified researchers throughout the world under policies established by the National Science Foundation and implemented through the Joint Oceanographic Institutions, Inc. and Texas A & M University.



The results of Scripps research are published in many different forms. These publications range from short contractual reports to long taxonomic descriptions. Scripps publications are distributed by subscription, exchange, or government contract.

Below is a complete listing of Scripps publications for fiscal 1989. Detailed information on the availability of each series is included.



APPENDIXES

APPENDIX A PUBLICATIONS

Bulletin

The *Bulletin of the Scripps Institution of Oceanography* is an irregularly published series for lengthy, in-depth scientific papers written by Scripps scientists. For information about subscriptions and a list of volumes available please write to University of California Press, 2223 Fulton Street, Berkeley, California 94720.

The most recent volumes are listed below.

- v.25 **Wilson**, George D. F. Systematics of a Species Complex in the Deep-Sea Genus *Eurycope*, with a Revision of Six Previously Described Species (Crustacea, Isopoda, Eurycopidae). 1983. 68p.
- v.26 **Matsui**, Tetsuo and Richard H. **Rosenblatt**. Review of the Deep-Sea Fish Family Platyroctidae (Pisces: Salmoniformes). 1987. 159p.
- v.27 **Wilson**, George D. F. A Systematic Revision of the Deep-Sea Subfamily Lipomerinae of the Isopod Crustacean Family Munnopsidae. 1989. 138p.

CalCOFI Publications

The work of the California Cooperative Oceanic Fisheries Investigations (CalCOFI), in which the Scripps Institution of Oceanography, the California Department of Fish and Game, and the National Marine Fisheries Service cooperate, is published in a variety of formats. Peer-reviewed scientific articles are published annually in the *California Cooperative Oceanic Fisheries Investigations Reports*. Maps of physical, chemical, climatological, and biological factors measured by CalCOFI researchers during the program's 40-year history are published irregularly in the *California Cooperative Oceanic Fisheries Investigations Atlas* series. Data reports, containing the processed data from specific cruises carried out under CalCOFI sponsorship, are published irregularly in the SIO reference series and in the CalCOFI data report series. To obtain copies of any of these publications, write to CalCOFI Coordinator, Scripps Institution of Oceanography, A-027, La Jolla, California 92093.



Contributions

The Scripps Institution of Oceanography Contributions is a compilation of selected reprints authored by the Scripps faculty and staff. This annual publication is available ONLY on an exchange basis to other scientific, research, and educational institutions. For exchange information please write to Scripps Institution of Oceanography Library, Exchange Department, C-075-C, La Jolla, California 92093.

The articles listed below were published in the 1988 volume and may also be found in the publications cited. Information about a specific reprint can be obtained by writing directly to the author in care of Scripps Institution of Oceanography, La Jolla, California 92093.

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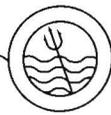
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Scripps Aquarium Newsletter

The *Scripps Aquarium Newsletter* is published quarterly by the Scripps Aquarium Associates and is sent to members. The newsletter contains articles and photographs featuring Scripps scientists and their research, aquarium events, associates' expeditions, and other

items of interest. For a free sample copy and membership information write to Scripps Aquarium Associates, A-007, Scripps Institution of Oceanography, La Jolla, California 92093.

Scripps Institution of Oceanography Reference Series

The reference series includes data reports, preliminary research reports, historical reports, and contractual reports distributed mainly under government contracts. There is no mailing list for this series, though many numbers are available from the National Technical Information Service, Operations Division, Springfield, Virginia 22151, by the AD number listed. Other inquiries about the *Scripps Institution of Oceanography Reference Series* should be sent to Technical Publications, A-033B, Scripps Institution of Oceanography, La Jolla, California 92093. Reference numbers listed below were issued in 1988.

- 88-1 **Pazan**, Stephen and Christopher **Noe**. User's introduction and guide to the Joint Environmental Data Analysis (JEDA) Center. July 1987. 13p.
- 88-2 **Fu**, T. C.-Y., R. E. **Flick**, D. R. **Cayan** and L. D. **Talley**. Southern California Bight sea level response to local atmospheric forcing. Center for Coastal Studies. January 1988. 155p.
- 88-3 **Pazan**, Stephen E. and Warren B. **White**. JEDA Center annual report on tropical Pacific subsurface thermal structure, 1986. Issued by the Joint Environmental Data Analysis (JEDA) Center in support of the Tropical Ocean/Global Atmosphere (TOGA) program. February 1988. 58p.
- 88-4 Physical, chemical, and current meter data; CalCOFI Cruise 7601, 6-7 January 1976; CalCOFI Cruise 7602, 16-20 February 1976; Cruise 7603 (TWATE III), 30 March-2 April 1976; Cruise 7604, 16 April-10 May 1976; and Cruise 7611, 11 November 1976. February 1988. 55p.
- 88-5 Physical and chemical data; Gulf Cruise 7303, 6-23 March 1973; and Gulf Cruise 7305, 23-26 May 1973. March 1988. 53p.
- 88-6 Physical and chemical data; Gulf Cruise 7404, 8 April-5 May 1974; and Gulf Cruise 7410, 2 October-3 November 1974. March 1988. 55p.
- 88-7 **Shor**, George G., Jr. and Tom **Beattie**. Research vessel *Robert Gordon Sproul* handbook 1988 edition. March 1988. 29p.
- 88-8 Physical, chemical, and biological data; CalCOFI Cruise 8709, 4-19 September 1987; and CalCOFI Cruise 8711, 13-28 November 1987. March 1988. 94p.



- 88-9 **Talley**, Lynne D., M. Margie **Martin**, Peter K. **Salameh** and the Oceanographic Data Facility. Transpacific section in the subpolar gyre—(TPS47): Physical, chemical, and CTD data report; *RV Thomas Thompson* TTI90, 4 August 1985–7 September 1985. March 1988. 245p.
- 88-10 **Talley**, Lynne D., Nancy **Collins** and the Oceanographic Data Facility. SAGA II: Physical, chemical, and CTD data report—*Akademik Korablev* 1 May 1987–9 June 1987. April 1988. 137p.
- 88-11 **Barnett**, Tim P. On the measurement of ocean current shears with synthetic aperture radar. April 1988. 35p.
- 88-12 **Jenkins**, Scott A., David W. **Skelly** and Joseph **Wasyf**. MARFAC sedimentation control site suitability study and conceptual system design. Center for Coastal Studies. May 1988. 85p.
- 88-13 Surface water temperatures and *salinities* at shore stations United States West Coast 1987; including *five-meter-temperatures* and *salinities* at Scripps Pier. July 1988. 37p.
- 88-14 **Hawkins**, James W. Cruise report PAPTUA Expedition leg 04 *RV Thomas Washington* 31 December 1985–27 January 1986; Pago Pago, American Samoa to Nuku'alofa, Tonga. July 1988. 54p.
- 88-15 **Duda**, Timothy F and Charles S. **Cox**. Quasi-Lagrangian measurements of microstructure and shear near a front in the coastal California thermocline. August 1988. 34p.
- 88-16 **Culver**, Richard Lee. Localizing and beam-forming freely drifting VLF acoustic sensors. Marine Physical Laboratory. September 1988. 149p. AD-A202-638.
- 88-17 **Shor**, George G., Jr. Chief Scientist's Manual 1989 edition (Including the laws, rules, customs, and procedures for work at sea on ships operated by the Scripps Institution of Oceanography). December 1988. 22p.
- 88-18 **Shor**, Elizabeth N. (editor). The water cycle: a symposium, Scripps Institution of Oceanography, January 23, 1988. Scripps Aquarium-Museum. December 1988. 74p.
- 88-19 **Sharp**, Sarah L. (Interviewer). Oceanography, population resources and the world. Roger Randall Dugan Revell. Preparation for a scientific career. Archives, Scripps Institution of Oceanography and Regional Oral History Office, U. C. Berkeley. November 1988. 102p.
- 88-20 **Sharp**, Sarah L. (Interviewer). Oceanography, population resources and the world. Roger Randall Dugan Revell, Director of Scripps Institution of Oceanography, 1951–1964. Archives, Scripps Institution of Oceanography and Regional Oral History Office, U. C. Berkeley. November 1988. 152p.
- 88-21 **Baker**, Karen S. and Raymond C. **Smith**. Bio-optical measurements from the FRONTS-88 Cruise 18 July–7 August 1988. UCMB data report. 1988. 150p.
- 88-22 Canceled

- 88-23 Physical, chemical, and biological data; CalCOFI Cruise 8801, 19 January–2 February 1988; and CalCOFI Cruise 8805, 28 April–12 May 1988. January 1989. 80p.
- 88-24 **Kuhns**, Kattie K. Bibliography of the Scripps Institution of Oceanography Reference Series 1984–1988. August 1989. 25p.

Sea Grant Extension Series

The Sea Grant Extension Series includes booklets, brochures, papers, and other publications produced by Sea Grant Extension at the University of California, Davis. Copies of the publications listed below can be obtained by writing Sea Grant Extension, University of California, Davis, California 95616.

- Caruso**, N., C. **Toole**, L. **Massey**, and C. M. **Deweese**. *Tests of an Expanded-Mesh Trawl Net to Reduce Fuel Consumption in the California Pink Shrimp Fishery*. Sea Grant Extension Program/Cooperative Extension, University of California, Davis. 1989. 9p.
- Johnson**, Leigh, and Connie **Ryan**. *California Coastal Waterfront Managers Survey, I. Executive Summary*. Sea Grant Extension/Cooperative Extension, University of California, Davis. 1989. 3p.
- Johnson**, Leigh, and Connie **Ryan**. *California Coastal Waterfront Managers Survey, II. Full Report*. Sea Grant Extension/Cooperative Extension, University of California, Davis. 1989. 26p.
- Price**, Robert. *Consumer Tips for Handling Seafood Safely*. Sea Grant Extension Program, University of California, Davis. Brochure. 1989.
- Price**, Robert. *Consumer Tips for Purchasing High Quality Seafood*. Sea Grant Extension Program, University of California, Davis. Brochure. 1989.
- Price**, Robert and Ed **Melvin**. *On-Board Handling of Albacore Tuna for Alternative Markets*. Sea Grant Extension Program, University of California, Davis. 1989. 93p.
- Price**, Robert. *Paralytic Shellfish Poisoning and Red Tides* (Revision). Sea Grant Extension Program, University of California, Davis. 1989. 2p.
- Price**, Robert. *Safe Handling and Storing of Seafood*. Leaflet. 1988.
- Price**, Robert and Pamela **Tom**. *Smoking Fish*. Leaflet. 1988.
- Price**, Robert. *Why Seafood Spoils*. Sea Grant Extension Program, University of California, Davis. 1989. 2p.
- Tom**, Pamela. *Sea Grant Extension Program*. Brochure. 1988.
- Toole**, Christopher, editor. *Proceedings of the Seventh California Salmon, Steelhead and Trout Restoration Conference*. Sea Grant Extension Program/Cooperative Extension, University of California, Davis. 1989. 52p.

Sea Grant Reference Series

The California Sea Grant Reference Series includes bibliographies, directories, symposium proceedings, and other institutional reports. The publications listed below can be obtained by writing the California Sea Grant College Program, A-032, University of California, San Diego, La Jolla, California 92093.

- R-026 **Amidei**, Rosemary. *Sea Grant in California: Twenty years of achievement*. Sea Grant report number R-CSGCP-026. 1989. 80p.
- R-027 California Sea Grant College Program. *California Sea Grant Program Directory 1989-90*. Sea Grant report number R-CSGCP-027. 1989. 28p.

Sea Grant Technical Series

The California Sea Grant Technical Series includes professional papers, scientific and technical reports, instructive manuals, and public policy papers resulting from Sea Grant-sponsored research. The publications listed below can be obtained by writing the California Sea Grant College Program, A-032, University of California, San Diego, La Jolla, California 92093.

- T-018 **Abbott**, Isabella A., editor. *Taxonomy of Economic Seaweeds with reference to some Pacific and Caribbean species*. Volume II. Results of an international workshop sponsored by the California Sea Grant College Program in cooperation with the Pacific Sea Grant College Programs of Alaska, Hawaii, Oregon, and Washington. Sea Grant publication number T-CSGCP-018. 1988. 264p.



APPENDIX B

ACADEMIC

STAFF

Academic Staff—July 1, 1988–June 30, 1989

All symbols and abbreviations are listed at the end of this section.

Henry D. I. **Abarbanel**, MPL, Physics
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&	Kenneth M. Watson , MPL, Physical Oceanography				
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APPENDIX C

AWARDS

AND

HONORS

Dr. Hassan Aref Elected a Fellow of the American Physical Society.

Dr. Wolfgang H. Berger Received the Maurice Ewing Medal from the American Geophysical Union.

Dr. Theodore H. Bullock Received an honorary doctorate degree from University of Frankfurt, West Germany.

Dr. Tsaihaw J. Chow Nominated for the Ishibashi Prize of the Research Institute of Oceanography in Kyoto, Japan.

Dr. Edward D. Goldberg Corecipient of the Tyler Prize for Environmental Achievement.

Dr. Walter F. Heiligenberg Received a MERIT award from the National Institute of Mental Health.

Dr. Devendra Lal Elected a foreign member of the American Academy of Arts and Sciences.

Received the Pandit Jawaharlal Nehru Award for Sciences from the State of Madhya Pradesh, India.

Dr. Jerome Namias Elected an honorary member of the Royal Meteorological Society of Great Britain.

Dr. John A. Orcutt Elected a Fellow of the American Geophysical Union.

Dr. Robert L. Parker Elected a Fellow of the Royal Society of London.

Joseph L. Reid Received the Albatross Award from the American Miscellaneous Society.

Dr. George N. Somero Received a J. S. Guggenheim Fellowship.

Dr. Fred N. Spiess Elected Vice Chairman of the UC Assembly and Academic Council.

APPENDIX D

CURRENT

FUNDS

Agency	Expenditures*	Percentage of Total
Federal Government		
National Science Foundation	22,115,206	31.67
Navy, Department of the	15,819,174	22.65
Commerce, Department of	2,129,277	3.05
National Aeronautics and Space Administration	1,893,725	2.71
Health and Human Services, Department of	1,326,339	1.90
Energy, Department of	778,076	1.11
Army, Department of the	1,614,050	2.31
Interior, Department of the	595,860	0.85
Air Force, Department of the	1,413,974	2.02
Other	- 36,698	- 0.05
Total Federal Government	\$47,648,983	68.22
State General Funds	14,996,304	21.48
Private Gifts and Grants	6,165,469	8.83
Overhead Funds	1,712,915	2.45
State of California	573,912	0.82
Endowment Funds	- 243,945	- 0.35
Local Government	48,113	0.07
Sales and Services	- 1,058,745	- 1.52
Total Current Funds Expenditures	\$69,843,006	100.00

*Includes overhead



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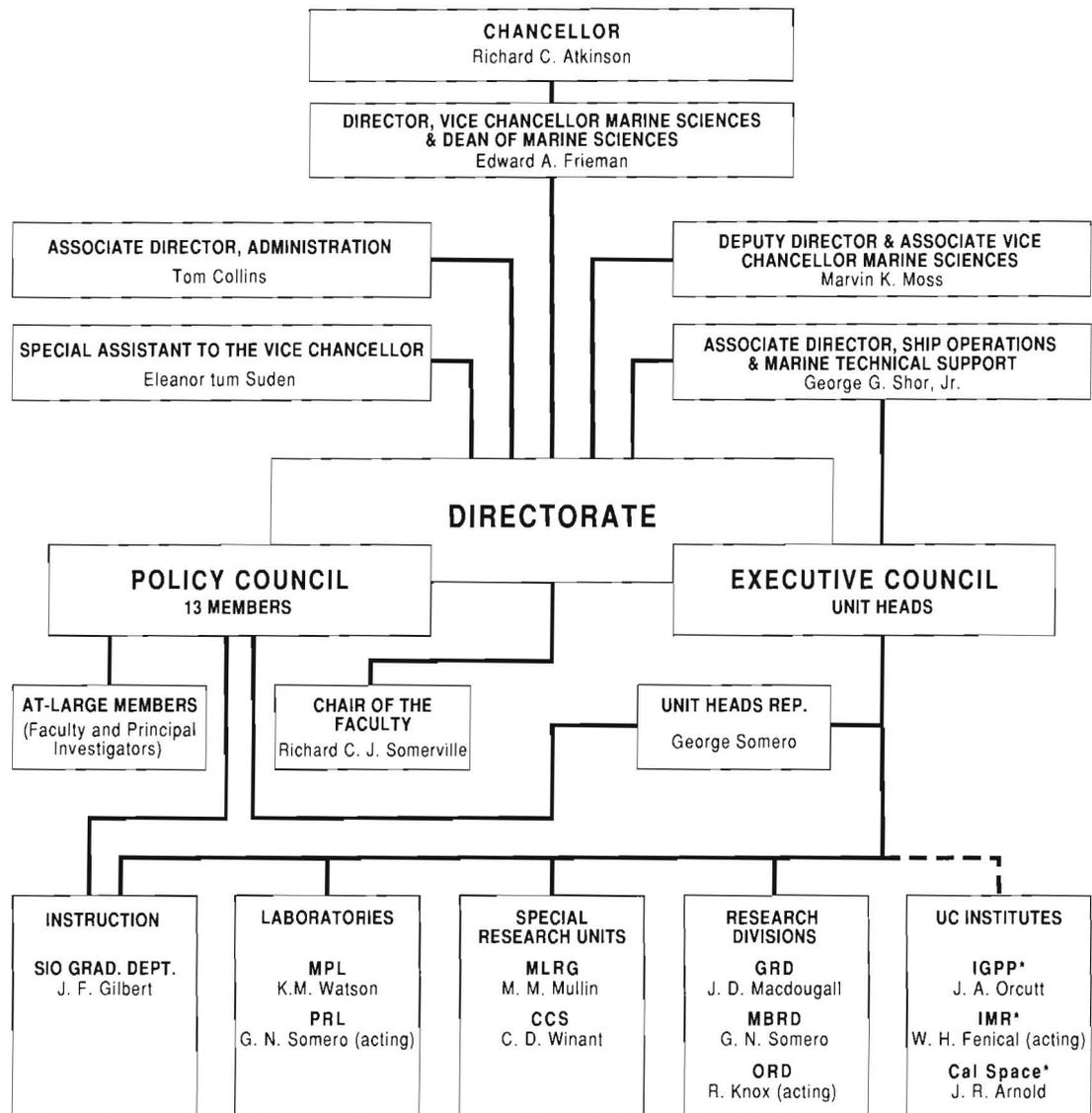
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* Current June 30, 1989

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Cal Space California Space Institute
 CCS Center for Coastal Studies
 GRD Geological Research Division
 IGPP Institute of Geophysics and Planetary Physics
 IMR Institute of Marine Resources

MBRD Marine Biology Research Division
 MLRG Marine Life Research Group
 MPL Marine Physical Laboratory
 ORD Ocean Research Division
 PRL Physiological Research Laboratory

*Reports to Vice Chancellor-Marine Sciences



APPENDIX F

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The Resources Agency of California
Department of Boating and Waterways
Department of Fish and Game
Department of Water Resources

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Forestry Service
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Army Corps of Engineers
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IN MEMORIAM

Michael A. Barnett. December 21, 1988. Michael Barnett, a former Marine Biology student, received his doctorate from Scripps in 1975. He had been working as an oceanographer at the National Oceanic and Atmospheric Administration.

Lawrence R. Blinks. March 4, 1989. Professor Blinks served Scripps as a member of the Bikini Scientific Resurvey in 1947 and was a participant in the 1966 maiden voyage of R/V *Alpha Helix* to the Great Barrier Reef. He was a distinguished cell and marine plant physiologist.

Arthur B. (Nick) Carter. September 16, 1988. Nick Carter came to Scripps in 1949 as its first shipboard radio officer. He provided communications for numerous expeditions and managed Scripps radio station WWD until his retirement in 1971.

John R. Cockle. August 17, 1988. John Cockle managed the San Francisco office of the Scripps Volunteer Observing Ship Program from 1976 through his retirement in 1987. He had continued meeting the ships as an unpaid volunteer.

Anthony (Tony) Correira. January 25, 1989. Tony Correira served as an able-bodied seaman from 1955 through 1989 with Scripps's fleet. The "Correira Guyot" in the Indian Ocean was named for him.

Robert F. Markworth. March 15, 1989. Bob Markworth worked as an administrative assistant in the California Space Institute from 1986 through 1989.

Benton B. Owen. May 7, 1989. Professor Owen was a research chemist and lecturer in the Marine Physical Laboratory from 1965 through 1969 and a research associate until 1974. A renowned electrolyte chemist, Professor Owen was a pioneer in considering pressure effects on chemical equilibrium in seawater.

Claude E. ZoBell. March 13, 1989. Professor Emeritus ZoBell came to Scripps in 1932 where for the next 40 years he served as professor of marine microbiology. Professor ZoBell was associated with Scripps longer than any other faculty member and was considered by many to be the "father of marine microbiology."



Benjamin M. G. Zwicker. July 2, 1988. Dr. Zwicker, a research chemist, was a research associate and visiting scholar in the Institute of Marine Resources from 1978 until his death.

*All correspondence pertaining to this specific report should be directed to:
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CODY AWARD



Robert and Bettie Cody look on as Dr. Frieman presents Dr. George Veronis with the Cody Award.

The first Robert L. and Bettie P. Cody Award in Ocean Sciences was presented by Scripps to Dr. George Veronis, professor of geophysics and applied mathematics, Yale University. Dr. Veronis is one of the founders of geophysical fluid dynamics. His papers on the dynamics and modeling of world ocean circulation are considered to be the foremost in the field.

The Cody Award, comprising a gold medal, a certificate, and a ten-thousand-dollar prize, was established by Mr. and Mrs. Robert L. Cody to honor outstanding scientific achievement in oceanography, marine biology, and the earth sciences. This international award will be presented biennially by Scripps to an individual whose originality and contributions in these fields merit international recognition. Selection for the award is made by a committee of scientists from Scripps and other academic institutions.

Robert Cody's great aunt, Mary Bennett Ritter, was the wife of Scripps's first director William E. Ritter.

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