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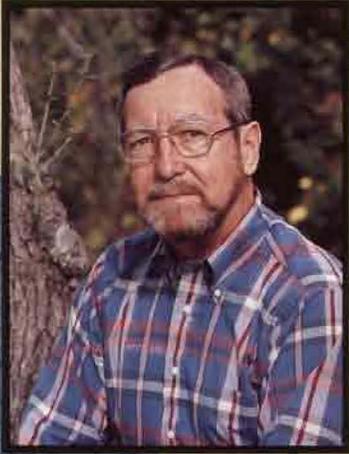


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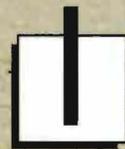
ANNUAL
REPORT

1-9-8-8

UNIVERSITY OF CALIFORNIA, SAN DIEGO



C. Colgan



INITIATED INTO BIOLOGY as a youth in the Cajun swamp country of Louisiana, Fred N. White has been conversant with nature throughout his life, finding some of his most rewarding times in the raw and marvelous majesty of the outdoors.

After holding faculty positions at universities and medical schools, including the UCLA School of Medicine, White joined the Scripps Institution of Oceanography in 1977 as director of the Physiological Research Laboratory. There he found people who shared his view that new insights into the workings of all living organisms could result from studying a wide range of species and environments.

An example of the valuable link between comparative physiology and medical practice comes from White's own research. His observations of the blood chemistry of cold-blooded animals showed that during exposure to varying temperatures, their blood pH varied in a predictable manner, a pattern which also improved performance in the hypothermic mammalian heart. He was aware that physicians attempted to maintain a constant blood pH while cooling patients' blood during cardiac surgery. He proposed, based on his studies of the mammalian heart, that allowing human blood pH to vary during cooling would help stabilize the heart. Most physicians now use this procedure to benefit hundreds of thousands of patients each year.

White was an extremely active member of the university community, serving on academic committees and teaching both undergraduates and graduate students. Among his numerous honors, he considers his greatest recognition to be the Student American Medical Association's Golden Apple Award for teaching.

Since retiring in July 1988 and moving to a small community in south-central Texas, White and his wife, Maxine, have retained links to the campus and San Diego by helping to raise funds for UCSD scholarships and by consulting on a new hummingbird aviary at the San Diego Zoo. Together, they plan to continue their lifelong activities of bird study and observing nature, in an area where wildlife is abundant.

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REPORT

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This is the University of California, San Diego, Scripps Institution of Oceanography Annual Report 1988 (for the year ending June 30, 1988). 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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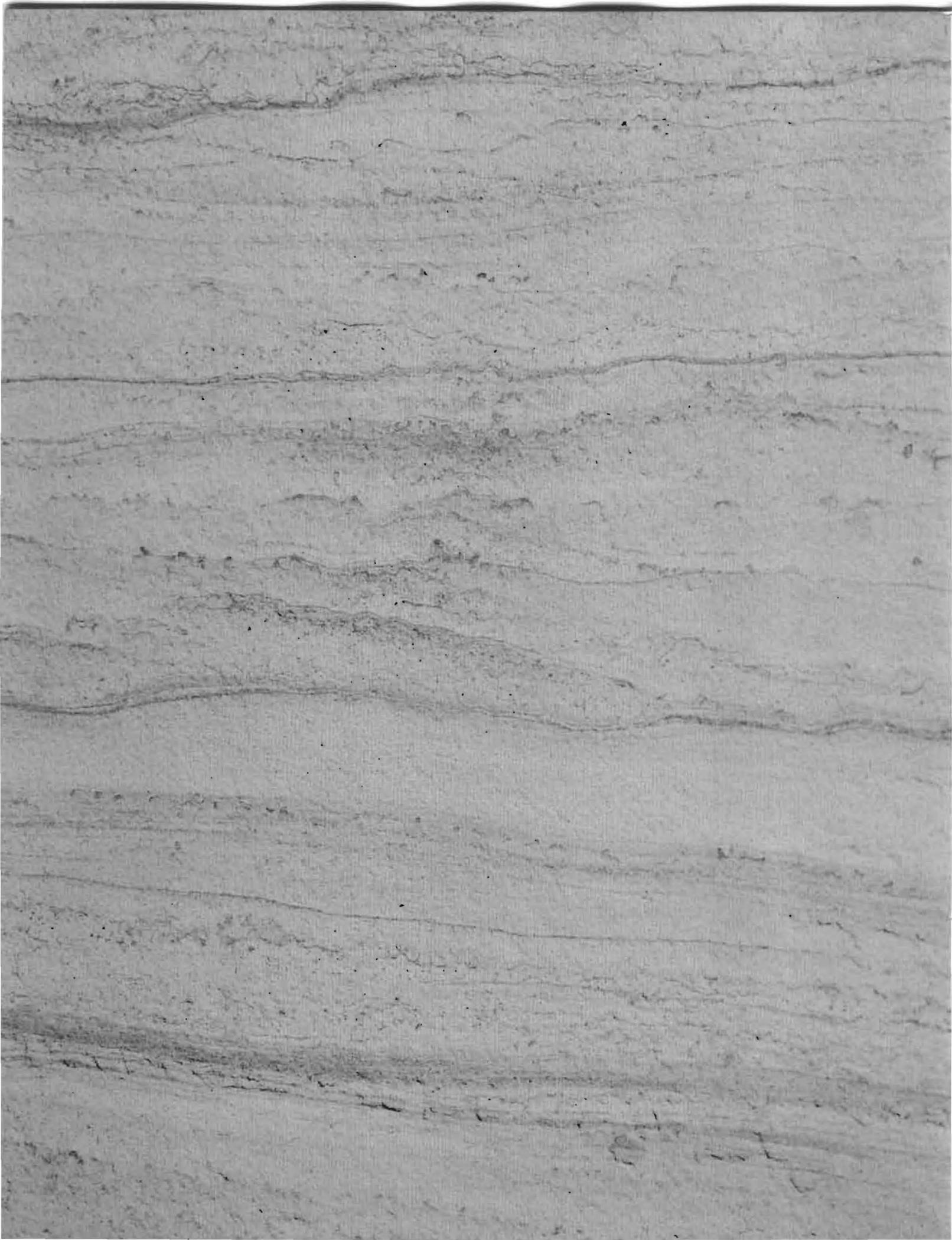
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INTRODUCTION

AT THE CLOSE of my second year as director, I find that international scientific concerns have increasingly drawn Scripps into multinational programs. We are now working with the Soviets on a major seismic program, and with several nations on a survey in the Strait of Gibraltar. Of course, the international Ocean Drilling Program continues, as does planning for the World Ocean Circulation Study and the Global Ocean Flux Study. I hope that the worldwide attention focused on global climate change will generate new funding and ship time for comprehensive studies. Scripps and two UC laboratories are already working together to model the environmental response to atmospheric CO₂ increase.

Here in La Jolla our major focus has been on research and education. We are at the start of a new development program, and involved with the initial reorganization of the institution, and with the dedication or renaming of several facilities.

In today's climate of declining state and federal support, it is increasingly important to generate funds from the private sector. To this end we have launched a development program that has already yielded funds for fellowships and research. We have also received an endowment for Scripps's first major international prize in marine sciences—the Robert L. and Bettie P. Cody Prize, a biennial \$10,000 award to recognize outstanding individual achievements in the ocean sciences.

A new, more representative form of government at Scripps is under way and has engendered some reorganization and a program to provide “hard” money for our academic researchers, to recognize and reward their excellence.

The Ellen Browning Scripps Memorial Pier was dedicated in the summer. Three campus buildings have been or will soon be renamed to honor Scripps professors. The Physical Oceanography and Space Sciences building is now William A. Nierenberg Hall; the Physiological Research Laboratory will be named Per F. Scholander Hall; and the Marine Biology Building will be Carl L. Hubbs Hall.

For us, two exciting events in 1987 were the eruption of Macdonald Seamount near R/V *Melville* during a Scripps Pacific Ocean expedition, affording us the opportunity to witness an island's birth, and our collaborative expedition with the Soviets to the USSR's Lake Baikal in Siberia.

The year was marked by many individual honors, which are listed in Appendix C. I do, however, want to mention the election of Russ Davis and George Somero to the National Academy of Sciences, bringing the total Scripps membership in this distinguished academy to eighteen.

As my tenure at Scripps continues, I am increasingly impressed with the breadth and depth of our research and the excellence of our training. My view is that Scripps can be even more important in the future than it has been in the past. I look forward to greater national and international scientific cooperation as we face the challenge of understanding our planet.

Edward A. Frieman
Edward A. Frieman, Director



B. Chih



HIGHLIGHTS

GIBRALTAR

EXPERIMENT

THE MEDITERRANEAN SEA loses more water by evaporation than it gains from fresh-water input because of its latitude and confined nature. Thus the sea is saltier and denser than water in the adjacent Atlantic Ocean. An international study, the Gibraltar Experiment, focused on the factors controlling this phenomenon. The exchange of water between the Mediterranean and Atlantic basins is an example of baroclinic flow caused by density differences. This has long interested fluid dynamicists because the phenomenon applies to atmospheric as well as oceanic problems.

The Strait of Gibraltar is nearly 60 km long, and 12 km wide at its narrowest section (Point Cires). A principal sill with a maximum depth of 300 m is located between Point Paloma (Spain) and Point Altares (Morocco). The channel varies in depth from 900 m at the Gibraltar-Ceuta section to the shoals at 350 m north of Cape Spartel.

The Gibraltar Experiment involved research teams from Canada, France, the United States, Spain, and Morocco. Focusing on subinertial flows with periods from a few days to a few months, the Scripps team studied the transport of heat and salt as well as water through the strait, the effect of tidal action, and the distribution of water masses (each water mass has unique temperature and salinity characteristics) involved in the exchange between the Mediterranean Sea and the Atlantic Ocean.

Current meters and instruments for measuring temperature, conductivity, and pressure were maintained on moorings along the sill for one year. Water surveys were also conducted from ships. Moorings were deployed and recovered from USNS *Lynch* as well as the Spanish hydrographic vessel *Tofino* and the Moroccan tug *Bouraz*.

Tidal variations in the flow through the strait were studied by the Gibraltar Experiment scientists. During spring tides currents are strong enough to reverse the di-

Ripple pattern indicates current movement through the Strait of Gibraltar as viewed from space. Spain is in the upper right. The Rock of Gibraltar is at the end of the peninsula forming the lowest point of the Spanish coast in the picture.



NASA

HIGHLIGHTS

Buoy being launched from R/V *Tofino* during the Gibraltar Experiment.



surface tide, affecting the entire water column; second, the internal tide, affecting the location of the interface, and therefore the thickness of different layers; and third, the strength of the tide (i.e., whether the tide is a spring or neap tide). These three effects can interfere constructively to create substantial modulation of exchange. At spring tides the currents are strongest, the excursion of the interface is largest, and the period when the lower layer becomes thick begins much earlier than in the neap tides. Thus during spring tides, substantially more deep outflow occurs with maximum tides. Because of the rugged, steep bathymetry of the sill region, most of the tidally driven outflow does not reenter the Mediterranean on the subsequent flood tide.

Scientists know that changes in atmospheric pressure over the Mediterranean influence the exchange of water through the strait. Conceptually the process is simple: if pressure increases over the Mediterranean Sea, it tends to force water out through the strait into the Atlantic, and vice versa. In order to further investigate and quantify this mechanism, the researchers obtained atmospheric pressure measurements over the Mediterranean every six hours for 64 meteorological stations bordering the sea. The data used came from the European Center for Medium Range Weather Forecasting, Reading, England.

The principal atmospheric pressure field over the Mediterranean Sea is homogeneous (i.e., the pressure increases or decreases simultaneously over the entire sea). Absolute pressure values are greater over the Ligurian and north Adriatic seas; smaller values are found toward the eastern Mediterranean; and minimum values occur near Cyprus. The researchers calculated the time series for the forcing of atmospheric pressure over the entire sea, and the subinertial transport through the Strait of Gibraltar. The atmospheric pressure variations are clearly correlated with transport through the strait.

rection of the mean flows so that, for example, during ebb tide (tide flowing out of the Mediterranean) there may be no inflow of Atlantic surface water. Similarly, at flood tide the tidal current may overcome the mean outflowing current. In addition to this significant modulation of the mean flow field by the surface tide, the accom-

panying internal tide causes large-amplitude displacements of the interface, separating the inflowing and outflowing water masses. One objective of the experiment was to quantify the tidal modulation of the exchanges of heat, mass, and salt between the two basins. There are several aspects to this modulation: first, as noted above, the

SEISMIC RESEARCH

WITH THE

SOVIET UNION

A simple, two-basin, two-strait model was designed to allow different mean atmospheric pressures over the eastern and western basins. Conservation of volume and hydrostatic pressure equations on the two basins and momentum equations in the straits are used to describe the gross movement of water at subinertial frequencies. Friction (which reduces flow) is included in the model to limit the flow through the Strait of Gibraltar.

Results of this simulation are then compared with observed flows. Although there are some discrepancies, the model seems to reproduce the observed transports at Gibraltar well, considering its simplicity. The model indicates that as a good first-order approximation, the system behaves like a forced simple oscillator subject to some friction.

A second objective of the hydrographic surveys was to examine the distributions of temperature and salinity (and thereby density) as well as some geochemical tracers in the vicinity of the strait and in the Gulf of Cadiz and the Alboran Sea. Vertical sections of density as a function of depth can, under certain assumptions, be related to the distribution of horizontal currents through the section.

This cooperative international project has elucidated much of the flow through the Strait of Gibraltar. Publications resulting from the experiments will be appearing during the next several years.

Jean Nichols

Suggested Reading:

Candela, J., C. D. Winant, and H. Bryden. Meteorologically forced subinertial flows through the Strait of Gibraltar. *Journal of Geophysical Research*. In Press.

Farmer, D. M. and L. Armi. The flow of Atlantic water through the Strait of Gibraltar. The flow of Mediterranean water through the Strait of Gibraltar. *Progress in Oceanography*. In Press.

OCCASIONALLY seismologists are called upon to detect underground nuclear weapons tests. A nuclear weapon detonated underground produces seismic waves very much like—but not exactly like—an earthquake. As anyone following the recent negotiation of the Intermediate-Range Nuclear Forces Treaty knows, a long-standing point of controversy in the debate about forming treaties with the Soviet Union has been verification. If we do agree to arms limitations with the Soviets, how can we verify that they are complying? And how do they know that we aren't cheating?

The "verification caveat" has also been applied to talk of limiting nuclear tests. Many arms control specialists think that a total ban or a limit on the size of nuclear weapons tests could significantly slow down the arms race. In 1963 the nuclear powers signed the Limited Test Ban Treaty ending testing in the atmosphere, in space, and in the oceans, sending testing underground.

In early 1987, Scripps seismologists, under the direction of Dr. Jonathan Berger, took a novel step in dispelling the verification caveat: in collaboration with scientists from the Institute of Physics of the Earth of the Soviet Academy of Sciences, they established three state-of-the-art seismic stations

within 200 km of the nuclear weapons test site in the Republic of Kazakhstan, on the steppes of central Asia. Since then they have recorded over a thousand seismic triggers. This data will be used to study the velocity structure, attenuation, and source characteristics of explosions and earthquakes in the Soviet Union.

Conceived and funded jointly by the Natural Resources Defense Council (NRDC: a private American environmental organization) and the Soviet Academy, the project entered its second year in 1988 with a plan to move the stations farther from the Kazakh test site to study wave propagation effects at larger distances. At the new stations, the NRDC equipment will be located together with the seismometers of a different design—deployed as part of the upgrade of the IDA (International Deployment of Accelerometers) network, a long-standing IGPP program funded by the National Science Foundation for basic research on earthquakes and earth structure.

The new stations will cover the bandwidth from DC to 80 Hz, allowing the group to study high-frequency ground motions from nearby local earthquakes or explosions as well as the modes of oscillation of the earth excited by large earthquakes, which can ring on for months after a seismic

HIGHLIGHTS

mic event. The easternmost station will be in Irkutsk on the shores of Lake Baikal in Siberia, and the westernmost in Obninsk near Moscow. The seismic data will be relayed by dedicated circuits to "network central" in Obninsk, which will also be in satellite communication with a data center in Washington, D.C.

In addition, the researchers operate three high-frequency seismic stations within 200 km of the American nuclear test site in Nevada. Comparison of the Nevada and Kazakh data has already shown differences between wave propagation in the two provinces. Seismic waves are attenuated more quickly with distance in Nevada, a tectonic region, than in Kazakhstan, a stable continental region. Attenuation differences can alter the size or "yield" that is estimated from the amplitudes of the seismic waves an underground test excites. Such differences will become extremely important when seismologists are called upon to judge whether a country is complying with an agreed-upon size for underground nuclear weapons tests.

Holly K. Given

Suggested Reading:

Berger, J. et al. A new US-USSR seismological program. *American Geophysical Union, Transactions*, v.68, no.8, 1987.

Garelick, Glenn. The grounds for a test ban treaty. *Discover*, v.8, no.6, 1987.

Example of path differences in seismic wave propagation. The two seismograms are from a nuclear explosion at the Kazakh test site. Both stations—labeled ARTI and CHUSAL—were approximately the same distance from the source (above), but in different geological environments. The CHUSAL record is depleted in high frequencies relative to ARTI because of higher attenuation along the ray path.

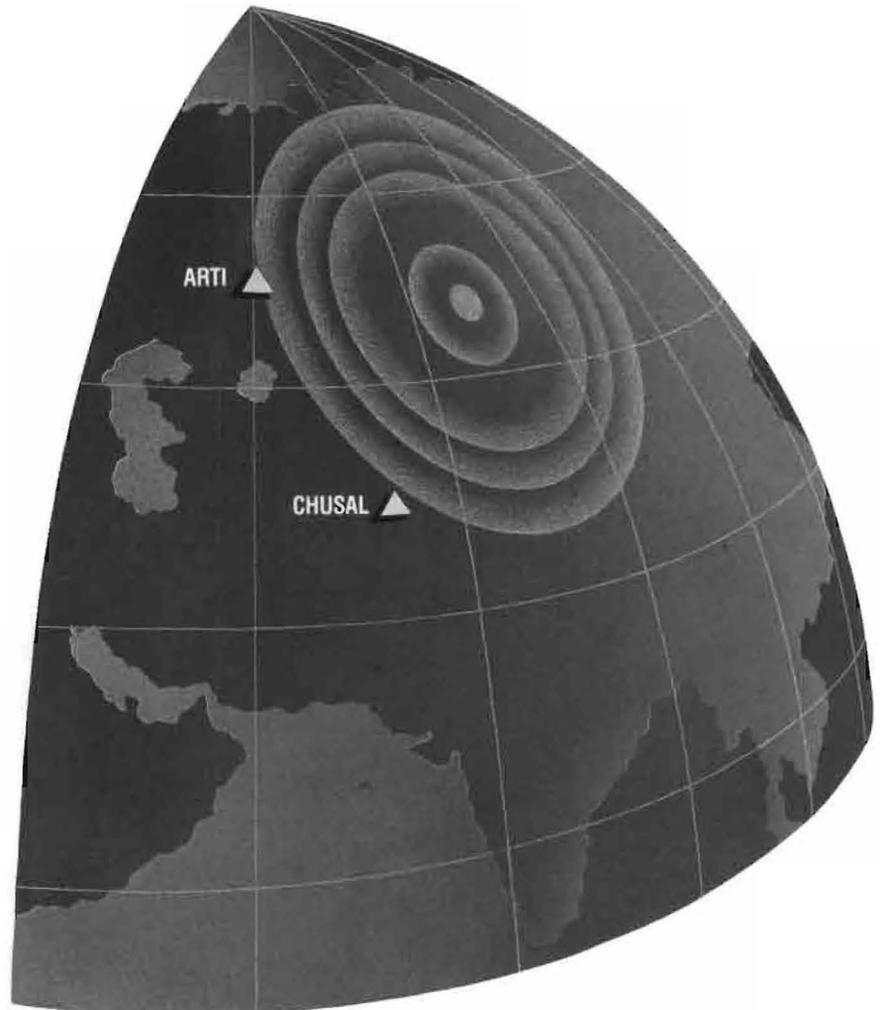
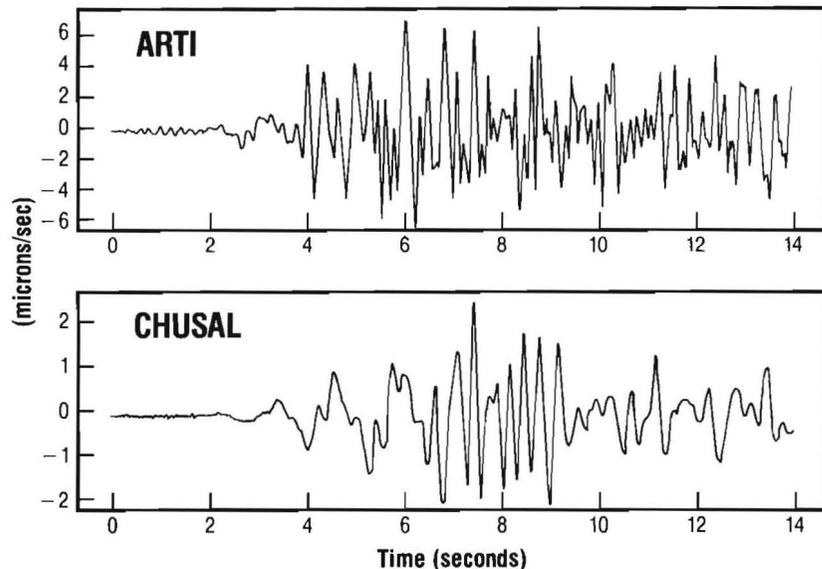


Illustration: Steve Cook

Nuclear Explosion at Two Equidistant Stations



Dr. Holly K. Given analyzes seismograms from a station in the USSR.





RESEARCH ACTIVITIES

MARINE

BIOLOGY

RESEARCH

DIVISION

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 Energy, Department of Commerce, 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.

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

The accumulation of arsenobetaine in commercial Australian lobster muscle prompted scientists in Dr. Andrew A. Benson's laboratory to study arsenic metabolism in marine algae. Until now, no arsenical metabolite that might lead to arsenobetaine has been detected. A common diatom, *Chaetoceros gracilis*, slowly accumulates a methylarsonium riboside, which can be degraded to arsenobetaine.

Dr. John L. Håkanson continued his survey of how energy stores (triglycerides and other lipids) in anchovy larvae relate to their survival and prediction of fishery size. Analyses of 2,000 larvae permit improved statistical study of collections from CalCOFI cruises and other cruises in coastal waters.

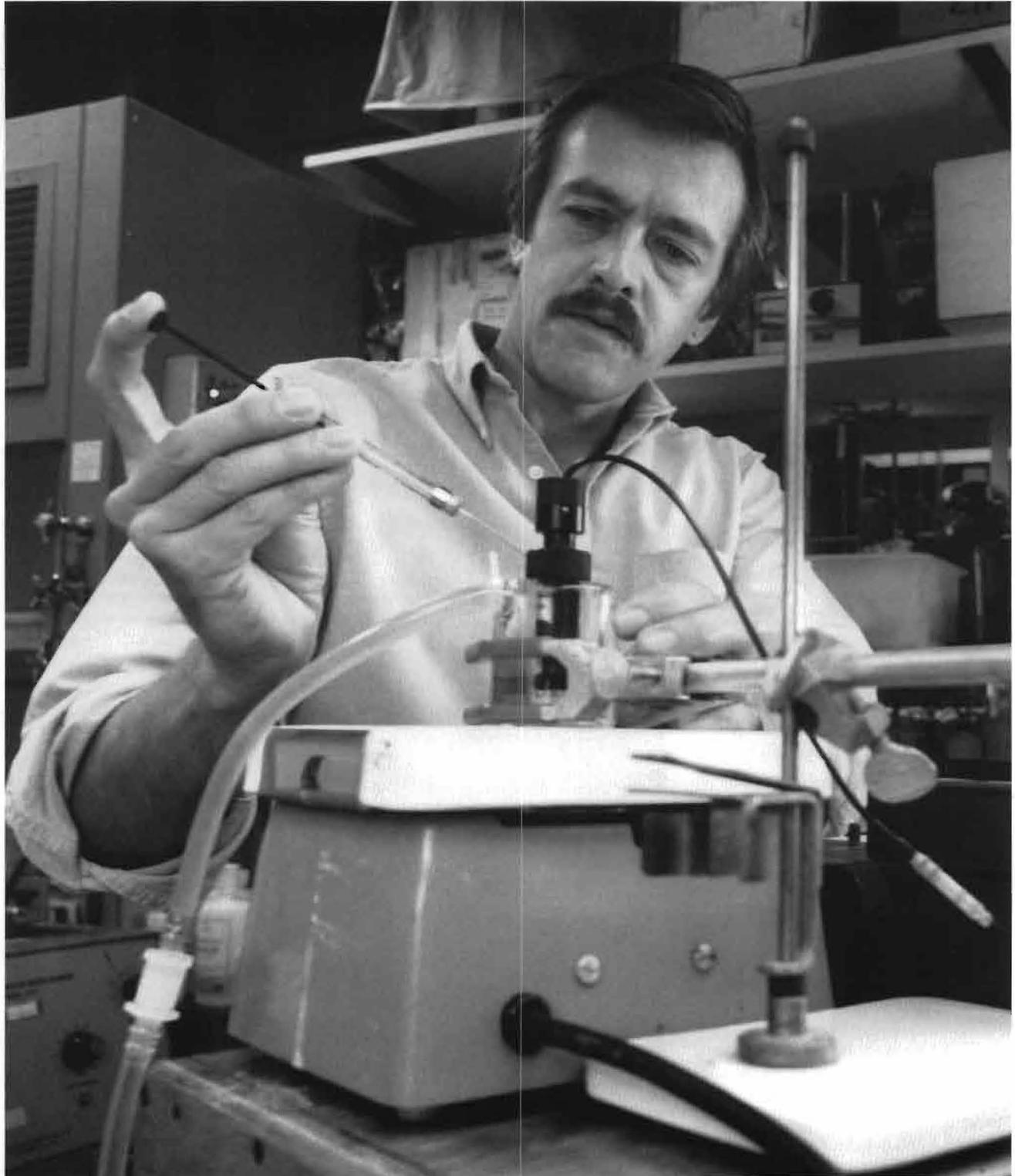
Dr. Lanna Cheng analyzed samples of the oceanic insect *Halobates* from the Atlantic Ocean, the Caribbean, and the Gulf of Mexico. Her samples were collected by colleagues from several institutions. In collab-

oration with a Texas A & M colleague, she is trying to discover whether sea-skater populations remain separate or are intermixed by currents.

Dr. Cheng is also studying how physical and chemical conditions affect the growth and lipid production of several lipogenic marine algae. Some algal species generate lipids as they grow; others only when they are starved for nitrogen. Some species may be good candidates for mass culturing to produce lipids for economic purposes.

Dr. Russell D. Vetter's group concentrates on the role of reduced sulfur compounds in the marine environment. Two graduate students accompanied Dr. Vetter on two six-week cruises to hydrothermal vent sites. There they studied the sulfur metabolism in animal and bacterial components of sulfide-consuming symbiotic invertebrates. In several species the animal host carries out the first steps in sulfide oxidation and then feeds less toxic, but still energy-rich, sulfur compounds such as thiosulfate to the bacterial symbionts. This oxidation protects the animal from the toxic effects of hydrogen sulfide. Graduate student Noemi C. Steiner is studying cell-division rates and growth

Dr. Russell D. Vetter injects radiolabeled hydrogen sulfide into isolated mitochondria to determine how some marine organisms generate energy from this toxic compound.



RESEARCH ACTIVITIES

regulation of endosymbiotic bacteria in animal host cells.

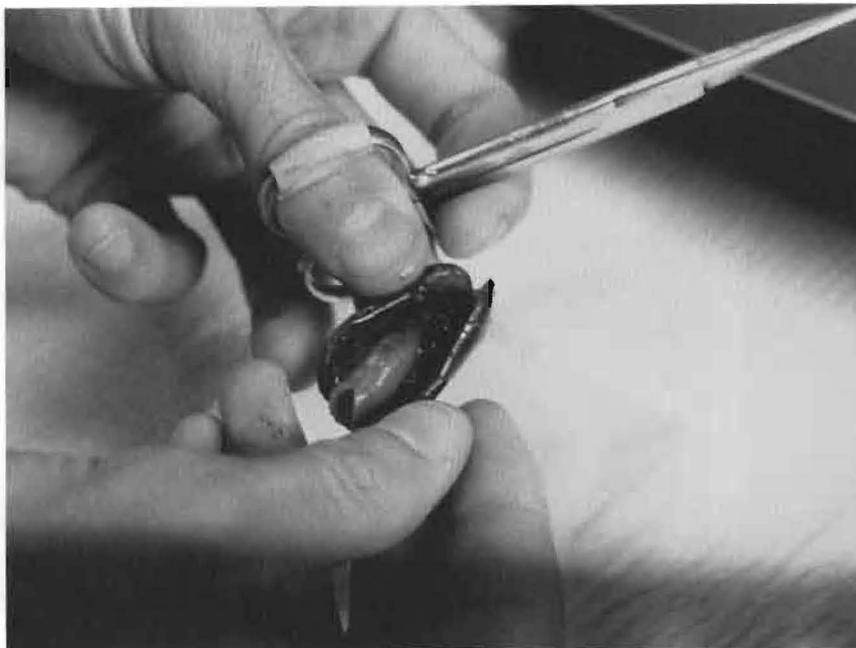
Recently Dr. Vetter's group isolated functional mitochondria from deep-sea organisms, facilitating the study of sulfur detoxification by mitochondria, and also opening new lines of research. Scientists can now study temperature and pressure effects on complex metabolic systems without having to recover and maintain whole animals under pressure.

Graduate student Teodora U. Bagarinao is studying how fishes and crustaceans adapt to high-sulfide environments like some estuaries and aquaculture ponds. Graduate student Patricia A. Matrai and Dr. Vetter completed a study on production of reduced sulfur compounds such as glutathione by marine phytoplankton. Graduate student Michele K. Nishiguchi continues this work by studying the role of intracellular, low-molecular-weight sulfur compounds as compatible osmolytes for stabilizing macromolecular structures in marine algae.

Dr. Horst Felbeck's group continued investigating the symbioses between chemotrophic bacteria and invertebrates. Graduate student Josephine D. Pino is studying the metabolic interactions between bacterial symbionts and their invertebrate hosts. Graduate student Jeffrey L. Stein researched the nitrogen assimilation pathways in a variety of symbiotic systems, detecting genes for nitrogenase in several mussels from hydrothermal vents and seep sites. Graduate student S. Craig Cary completed his study on the nutritional requirements of a mussel with methane-oxidizing symbionts.

Dr. Ralph A. Lewin is studying the taxonomy of picoplankton algae, which are the smallest autotrophs living at the ocean surface. They have never been properly characterized. He also concentrates on the ecology of *Prochloron*, the photosynthetic partner in a number of symbiotic associations with tropical didemnids (colonial ascidians). Dr. Lewin is using ecological

Graduate student David B. Wilmot dissects a gutless clam, *Solemya reidi*, from the Los Angeles sewage outfall to study bacterial symbionts. He then isolates the bacteria (below left) and prepares the metabolic chamber (below right).



and physiological features—including auxotrophy and facultative heterotrophy—to classify green planktonic flagellates in the genus *Tetraselmis*. He is seeking taxonomically useful correlations between some of these features and the isozyme patterns previously studied in these organisms.

Ecological energetic studies of deep-sea communities continue in Dr. Kenneth L. Smith's laboratory. Active and passive transport of organic matter from mesopelagic to abyssopelagic depths is being investigated. The importance of vertically migrating animals in transporting organic matter through the water column is demonstrated by free-vehicle acoustic instrumentation coupled with time-series net sampling. Graduate student Waldo W. Wakefield is studying how planktotrophic development in slope-dwelling megafauna affects the seasonal transport of organic matter through the water column. Graduate student Ronald C. Kaufmann continues to investigate the sensory biology of scavenging amphipods and their importance in deep-sea communities. Other scientists are studying the transport of organic matter through the water column in the eastern and central North Pacific.

Dr. George N. Somero's group is studying biochemical adaptations that enable marine organisms to thrive under diverse environmental conditions. Food availability is one critical environmental factor for establishing the biochemical properties of marine organisms. Drs. Mary Sue Lowery and Susan J. Roberts showed that starvation of marine fishes leads not only to marked changes in the activities of metabolic enzymes, but also to shifts in the enzyme localization within muscle cells. These changes in enzyme localizations (compartmentalization) are mediated by intracellular acidity and the concentrations of low-molecular-weight organic substances that regulate enzymatic activity. These studies have important implications for the roles that enzyme localization may play in diverse physiological contexts.

Also in Dr. Somero's group, graduate student Allen G. Gibbs discovered a new example of biochemical adaptation to high hydrostatic pressure. A major ion-regulation enzyme system in fish gills—the sodium + potassium adenosine triphosphatase—exhibits a sharp response to pressure. Shallow-living fishes have high pressure sensitivities; deep-living fishes have low sensitivities. Dr. Margaret J. McFall-Ngai investigated the fine-scale molecular adaptation of an enzyme from barracuda adapted to different temperatures. Her studies reveal fundamental changes in protein structure that are involved in species-specific differentiation at the molecular level. Graduate student Sandor E. Kaupp continued his studies of biochemical changes during early development in marine fishes. He found that in larval marine fishes the biochemical properties, like enzymatic activities and ribonucleic acid concentrations, are similar among diverse species. However, during maturation, marked interspecific differences quickly develop that relate to the species' lives (for example, pelagic versus sedentary existence).

Dr. Joan G. Stewart studies how individual plant species' morphology and life histories affect the composite form of intertidal vegetation. Boundaries between several dominant taxa, and seasonal fluctuations in short-lived species, depend on direct interactions between plants as well as on tolerances of physical factors. Many properties of the system, including invertebrate abundances, are regulated by predictable patterns of sand movement and deposition.

Scientists in Dr. Victor D. Vacquier's laboratory study the biochemistry of sea urchin fertilization. They focus on identifying the proteins of the sperm cell membrane that activate flagellar motility, induce the acrosome reaction, and induce the phosphorylation of histones in the sperm nucleus. Monoclonal antibodies have been produced that bind to a sperm membrane protein of 210,000 molecular weight. Antibody binding opens calcium channels and acti-

vates adenylate cyclase, which in turn activates a cyclic AMP-dependent protein kinase that phosphorylates histone H1 on a single site. The individual components of this chain of linked reactions are being studied to clarify how an event on the outside surface of a cell triggers changes in the cell nucleus.

Dr. Benjamin E. Volcani's group investigates the mechanisms by which silicon regulates gene expression and DNA replication in diatoms. Currently, two native plasmids—pCf1 and pCf2—found by this group in the diatom *Cylindrotheca fusiformis* are being studied. A visiting scientist has determined how much homology pCf1 and pCf2 share with each other and with diatom chloroplast and nuclear DNA. Dr. Mark M. Hildebrand has been determining the intracellular location and copy number of the two plasmids. Dr. Robin W. Ord, Dr. Hildebrand, and a colleague used these plasmids, as well as other fragments of diatom DNA, to construct potential diatom transformation vectors, which contain the chloramphenicol acetyltransferase (CAT) gene under the control of various eucaryotic promoters. Using these vectors, Dr. Ord and a colleague are attempting to render diatom cells chloramphenicol-resistant. Dr. Paul P.C. Lin has characterized two novel cyclic AMP-dependent protein kinases in *C. fusiformis* and regulatory domains on the same polypeptide chain. The role of these kinases in the silicon-regulated cell cycle of this diatom is being investigated.

Dr. George D. F. Wilson has completed a major work on a large family of natatory deep-sea isopods, the Munnopsidae. His other research on Isopoda includes a collaboration with Russian colleagues to revise the deep-sea genus *Microprotus*; a systematic review of the common shallow-water family Janiridae; and a detailed description of an unusual gastrointestinal system in a tiny local isopod, *Pleurocope* n.sp. Dr. Wilson, in collaboration with Dr. George Sugihara, has produced a computer program to estimate theoretical diversity in species-rich animal communities.

MARINE

LIFE

RESEARCH

GROUP



THE MARINE LIFE RESEARCH GROUP (MLRG) continues a 38-year search for the causes of large-scale, long-term fluctuations in the physics, chemistry, and biology of the California Current, which often have important economic consequences for California. Departures from long-term means can be interpreted as symptoms of change in the local, regional, and global ecosystem, and may be powerful indicators for making predictions and forming hypotheses.

To study the physics and ecology of the California Current, MLRG scientists and colleagues from the California Department of Fish and Game and the Southwest Fisheries Center made four cruises in California coastal waters. The subsurface water temperature off the coast of southern California was anomalously warm from mid to late 1987, suggesting a weak but positive correlation with a mild eastern Pacific warming trend. These conditions promote the continued recovery of the sardine population, which began in the late 1970s.

Six other cruises were made to define the population biology, community structure, food chains, physical disturbance mechanisms, and natural history of marine organisms and the physical environment in which pelagic plants and animals live.

Programmer Judy D. Illeman and Dr. Teresa K. Chereskin calibrate a drifter for use in a California Current study.

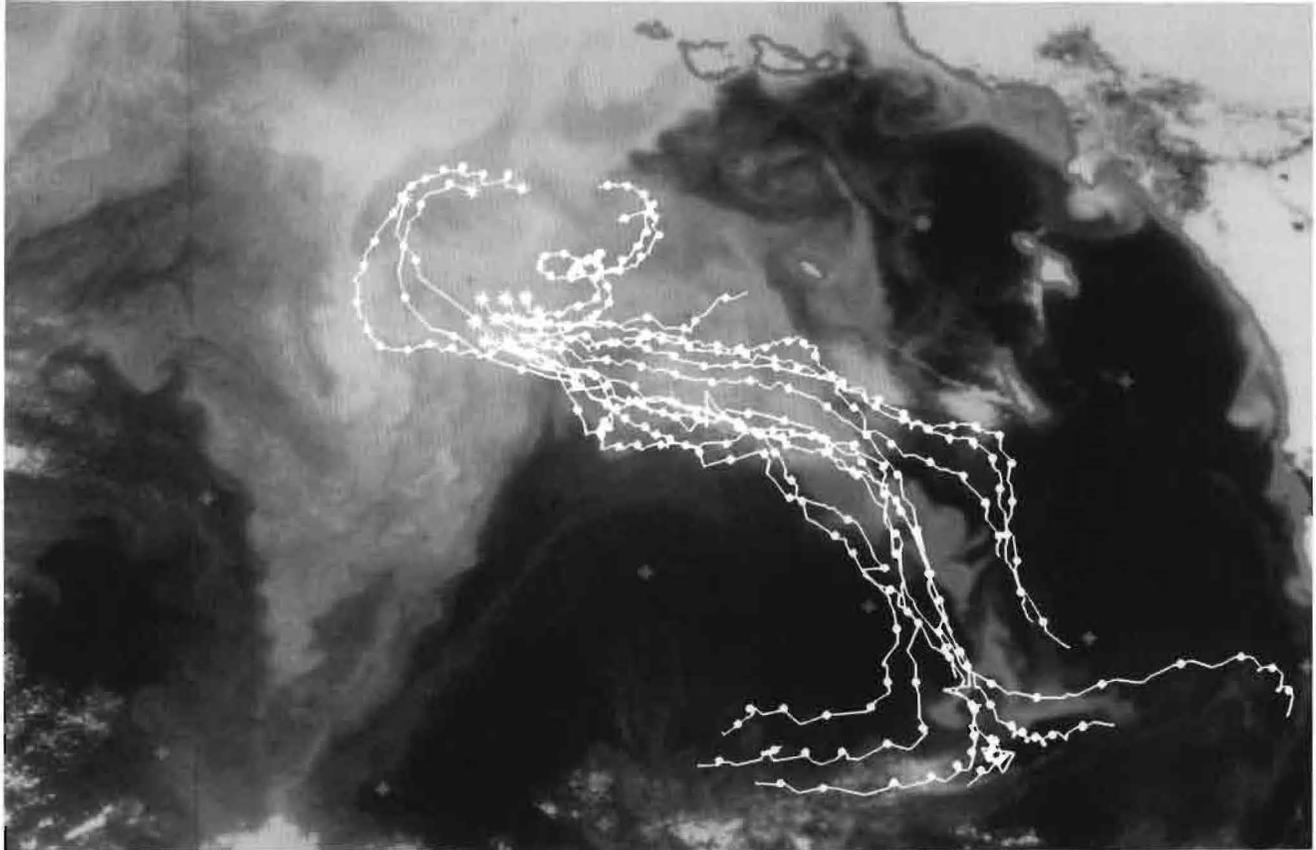


Dr. John A. McGowan has been developing quantitative descriptions of pelagic community structure. Extensive theoretical bases suggest patterns in species dominance and in spatial structure. The structural features are thought to be evolutionary and are intimately linked with the dynamics of community systems. The search for patterns in mobile, pelagic communities is the first step in determining what regulates the system and gives it resilience in the face of environmental change. The goal is to determine structure and then ask three questions: Why is it the way it is? What sort of perturbations will change it? What directions will the changes take? Once these questions are answered, detailed studies of the specific mechanisms responsible for buffering the system against change can be designed.

Results indicate that the patterns of pelagic system structure and stability are very time-space dependent. But there are regional variations: structural patterns in the California Current differ strongly from patterns in the Central Gyre of the North Pacific. In spite of large-amplitude variations in the California Current and small-amplitude variations in the gyre, both systems appear stable. However, they do differ strongly in diversity and dominance. In this regard, the pelagic regional systems resemble terrestrial forests' regional patterns. This similarity may imply causation.

Dr. Edward Brinton focuses on the growth rates and life spans of euphausiid crustaceans. He describes not only population dynamics in individual species, but also why some species in a given body of water are so much larger than other,

Satellite photo of the California Current/Southern California Bight area taken during the time of the Ensenada Fronts Cruise. Lines indicate buoy tracks.



Scipps Satellite Facility

closely related species found there. Off Baja California and California, *Euphausia gibboides* and *E. eximia* grow to 30 mm, or twice the body length and 10 times the weight of co-occurring *E. recurva* and *E. hemigibba*. Population structures are being compiled across station grids in the California Current for the years of differing oceanic climate (including the 1982–1984 El Niño). Cohorts distinguished in month-to-month, length-frequency distributions show that some large species reach maturity—about two-thirds of their maximum body size—in one year. After this spurt, growth slows during a protracted period of reproduction extending to another year.

Dr. Mark D. Ohman is working on the population biology of copepods. He has elucidated the numerous avoidance, escape, and defense responses that individual

zooplankters use to fend off a predator during different steps in the attack. Such behavioral responses may stabilize or destabilize population changes through time. Dr. Ohman has also discovered that day-night changes in feeding behavior in four species of planktonic copepods from the California Current explain more of the variance in ingestion responses than do changes in food supply. Dr. Ohman and colleagues from New Zealand have reared and described the developmental stages of the three dominant species of calanoid copepods found in New Zealand waters.

Dr. Loren R. Haury, working with two Johns Hopkins University colleagues, is studying how turbulent dissipation and vertical current shear affect zooplankton distributions in the surface layers of the ocean. Biological and physical data col-

lected off Monterey Bay, California, show how increased physical mixing caused by high winds and shear brings together weakly swimming zooplankton species that normally live at different depths under more benign conditions. Strongly swimming species, however, can counteract the physical effects and remain within their preferred depth zones. This differential impact of physical forces on community structure should profoundly affect how communities function.

Dr. Thomas L. Hayward studies the processes regulating primary production and the distribution of plankton in the ocean. His work confirms that the rate at which nutrients are supplied to the euphotic zone is a major determinant of primary production. He is now studying the physical processes that regulate the nutrient supply, and

RESEARCH ACTIVITIES

he is seeking causal physical structure from the biological pattern.

Dr. Angelo F. Carlucci has discovered that high primary production in the springtime is reflected in the fall by high microbial numbers, high biomass of bacteria, and high amino acid metabolism in the deep waters and benthic boundary layer of the Santa Monica Basin. The energy source for this increased microbial activity is provided, in part, by the sinking organic particles produced by primary production, grazers and other organisms of the higher food web, and their fecal pellets. Particles reaching the sediments are transformed by the benthic microbes; some of the particles and their decomposition products are re-suspended into the benthic boundary layer.

In a 20-year analysis of vertical distribution of phytoplankton in the Central North Pacific, Dr. Elizabeth L. Venrick has discovered a major floral shift. This shift occurs about 100 m deep, near a conspicuous layer of elevated chlorophyll. In earlier studies it was unclear whether the chlorophyll maximum layer was more closely related to the shallow flora, the deep flora, or the transition zone between them. Analysis of additional material made it possible to define key species for each assemblage. The vertical distributions of these species indicate that the increased chlorophyll abundance at the top of the maximum layer closely parallels the increased abundance of deep species. The chlorophyll maximum layer comprises species characteristic of the deep assemblage, with only insignificant numbers of shallow species. These observations are inconsistent with some of the earlier hypotheses about the formation of maximum layers.

Tetsuo Matsui studies the life histories of the sablefish (*Anoplopoma fimbria*) and the grenadier (*Coryphaenoides acrolepis*). He analyzed catch records of vertically set, free-vehicle longlines deployed in 200–3,200 m of water off the Californias in the 1960s and 1970s. Most grenadiers were taken on hooks that were 14–40 m off the

bottom, whereas most sablefish were nearer the bottom. Isolated catches of one or more individuals of both species were found along the entire line, to 100 m from the bottom. This suggests that these species swim some distance off the bottom. In addition, individuals of the same species and the same gender tended to cluster together.

Drs. Dean H. Roemmich and Bruce D. Cornuelle are conducting a multiyear study of the time variations of ocean circulation in the Central Pacific Ocean. They collected temperature and sound velocity data between 37°S and 22°N. Results of a two-year pilot study show a southward shift in the center of the southern subtropical gyre, coincident with the 1986 El Niño-Southern Oscillation episode.

Dr. Teresa K. Chereskin has been evaluating the water-following characteristics of freely drifting, weighted drogues (called Lagrangian drifters) tethered to surface buoys. With these drifters, one can study the divergence and vorticity of the upper ocean. Dr. Chereskin's results have been used to design drifters for experiments in regions of large near-surface shear, such as the equator and the California Current. She is also using acoustic Doppler profiling data to estimate the horizontal wavelength of inertial waves. Her early results demonstrate the existence of inertial waves that share a horizontal scale with synoptic storms.

Dr. Pearn P. Niiler designed drifting buoys that are drogued in the mixed layer, and which are tracked by, and transmit subsurface data to, the ARGOS satellite system. Early data and analyses from 237 drifter tracks in the eastern Pacific show that off Baja California the horizontal diffusion of nutrients, temperature, and salinity on the ocean surface is not uniform. The data also demonstrate that diffusion rates vary by a factor of ten or more, depending primarily on the strength of mesoscale eddies. Stronger diffusion rates are seen near the coast.

Dr. James J. Simpson has embarked on three cruises in the coastal waters of the

Southern California Bight region, sampling the subsurface of the marine environment and using satellite information to study the California undercurrent, surface velocity, and the dynamics of mesoscale eddies. New methods for concurrently analyzing remotely sensed and ground-truth data, using powerful statistical techniques and high-speed computational facilities, have made it possible to perform integrated analyses that were previously impractical.

Joseph L. Reid, using the distributional patterns of such tracers as temperature, salinity, oxygen, and nutrients, has described the large-scale flow patterns of the South Atlantic Ocean. Reid characterized the western boundary currents along the coast of South America, along the Mid-Atlantic Ridge in the Angola and Cape basins, below the ridge depth, and in a deep, northward flow along the eastern side of the Brazil Basin.

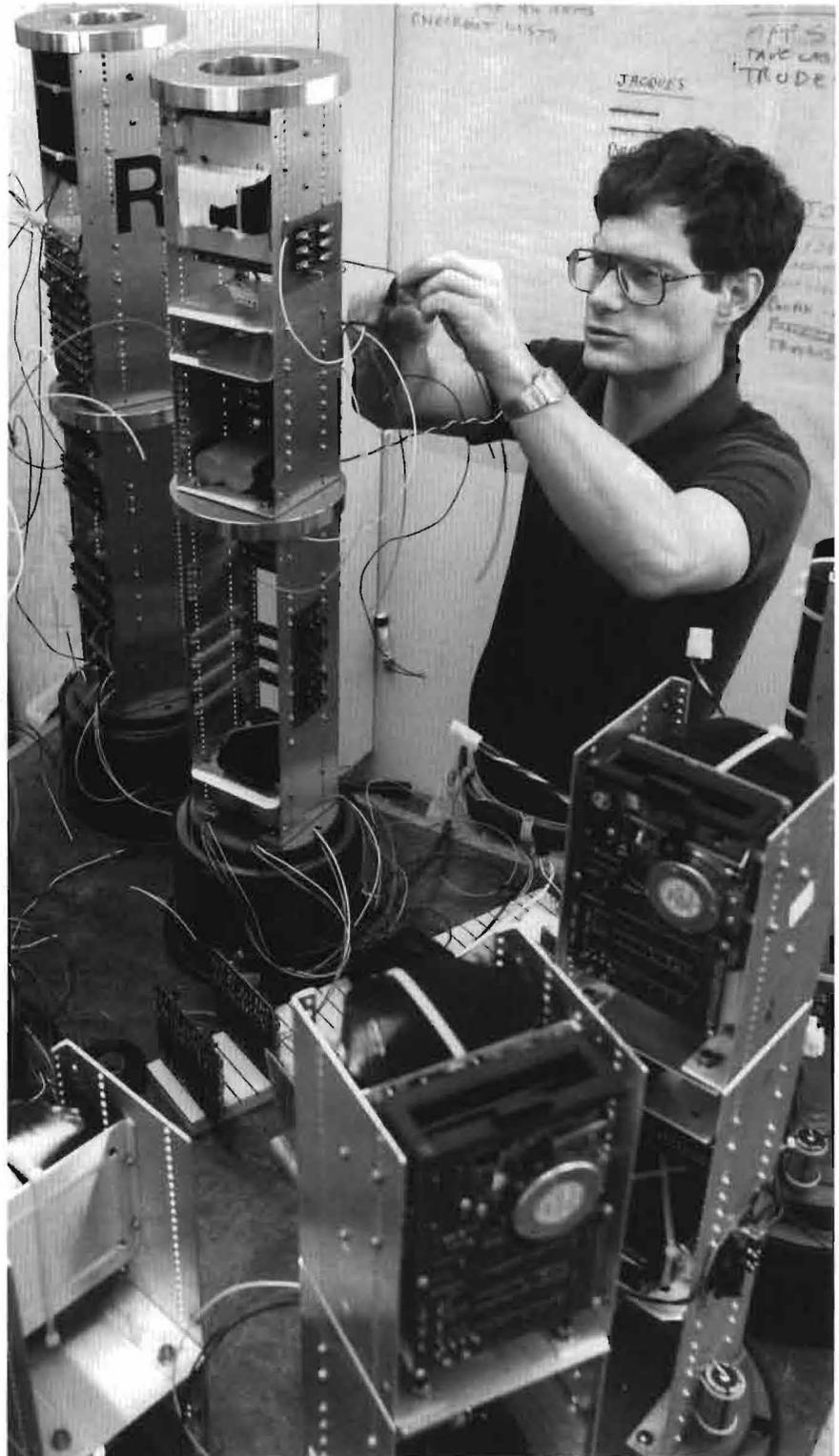
MARINE PHYSICAL LABORATORY

Dr. Spahr C. Webb prepares a group of his new pressure instruments for a major cruise.

SCIENTISTS AT THE Marine Physical Laboratory (MPL), directed by Dr. Kenneth M. Watson, study ocean acoustics and develop acoustic instrumentation. MPL researchers also investigate seafloor geology and geophysics, ocean dynamics, signal processing, and ocean technology.

New instruments and new methods of deploying existing instruments were developed by Dr. Spahr C. Webb. A long, rigid tube with a transducer at the midpoint was used to measure the pressure difference between two points on the seafloor separated by a few hundred meters. This "gradient pressure gauge" can measure signals near the ambient seismic or acoustic seafloor noise levels in a broad band from about .01 Hz to .5 Hz. Dr. Webb and a colleague conducted a joint experiment at two sites in the Pacific northeast. They observed very-low-frequency signals in shallow water and used explosive shots to test the performance of the gradient pressure gauge. One instrument was also deployed on the Galápagos Ridge, the first bare-rock site for any deployment, which should differ acoustically from sedimented sites.

An experiment was conducted to study the sources and propagation of very-low-frequency (below 1 Hz) acoustic, seismic, and hydrodynamic signals and noise on the



RESEARCH ACTIVITIES

deep seafloor. A 17-instrument large-aperture array was deployed; it included 5 Scripps ocean-bottom seismometers, 4 electric-field instruments, and 8 pressure-gradient instruments. This experiment coincided with a deployment of surface-scattering sonars from FLIP by other MPL researchers. The surface wave data derived from the sonars, and the pressure measurements from the seafloor will be examined for mechanisms that generate low-frequency sound.

Drs. John A. Hildebrand and Fred N. Spiess developed an instrument package to measure the earth's gravity field on the ocean bottom. This instrument makes accurate and fine-scale gravity measurements in the deep sea. The instrument includes a LaCoste and Romberg gravimeter, a sonar navigation package, and a precision pressure gauge. The seafloor gravimeter was tested off the California coast from R/V *Mehille* in 2,500 m of water, and measured with an accuracy of 0.05 mGals. Seafloor gravity readings were conducted with as little as 5 minutes bottom time, although it was found that the ship's station keeping was adequate to extend bottom time to over 45 minutes. In the spring the gravimeter was used from R/V *Thomas Washington* in water 5,000 m deep in the Northeast Pacific at 35°N, 132°W. Seafloor and shipboard gravity measurements were made simultaneously to allow comparison for calculating the Newtonian gravitational constant G . The value of G may depend on the scale length of the measurement, and an oceanic measurement of G covers several kilometers.

The seafloor gravimeter also facilitates study of fine-scale features on the ocean bottom that extend to 100 m, whereas shipboard gravimeters are limited to features that are roughly the scale of the water depth (about 5 km). Ridge-crest vent fields are seafloor structures that change significantly over a few hundred meters. In such places the seafloor gravimeter can help researchers delineate the underlying density structure.

John T. Lyons and a student (*in background*) wind cable before deploying it on the seafloor.



The seafloor vehicle RUM III was initiated this year in the Catalina Basin, 40 km off southern California. During the 24 days on station, RUM III was in the water 40 percent of the time and on the bottom for 80 hours. Two types of operations were conducted during the trip. The major effort was a pilot sedimentation study in preparation for a more extensive expedition to a 4,500-m-deep manganese nodule field. The second operation was the test deployment of acoustic sensors. The tasks accomplished in the 1,200-m-deep water included obtaining 32 box cores of treated and untreated sediment, making 9 artificial mounds, placing a "pit mimic" dish and two colonization trays on the seafloor, and deploying two Swallow float acoustic experiments. The RUM III telemetry system has been improved so it can operate over 7,000 m of coaxial cable at depths of 6,000 m. A tether-cable swivel with slip rings has been added

to relieve the torque of the longer cable. An additional TV camera and associated pan-tilt mechanism reduces task time and operator fatigue by providing two orthogonal views of the work area. These improvements were tested in 1,500 m of water. RUM III has been designed, fabricated, and operated under the direction of Dr. Victor C. Anderson.

Dr. Robert Pinkel's upper ocean physics group developed new instrumentation and analyzed data. They focused on clarifying the relationship between shear ($\frac{\partial u}{\partial z}$) and the vertical component of vertical strain ($\frac{\partial w}{\partial z}$) in the upper ocean. Graduate student Jeff T. Sherman has created a pulse-to-pulse coherent sonar for measuring the small-scale shear. This device has a maximum range of 30 m, with one-cubic-meter resolution. When Sherman compares the coherent sonar's shear measurements to profil-

ing CTD observations of isopycnal vertical displacement and strain, the agreement is good. However, significant differences exist. If CTD fixed-depth measurements of the density profile are used instead of the semi-Lagrangian isopycnal measurements, the agreement between density and shear statistics is improved.

A coherent sonar was modified for the coming Arctic experiment. The sonar will be operated in a combined coherent/incoherent mode, with short-range (30 m), very-high-resolution sampling interspersed with longer-range (400 m) probing. This sonar will be used in the Arctic to measure both small-scale and large-scale shears at an ice camp north of Spitsbergen.

Under the guidance of Dr. Jerome A. Smith, a new high-resolution surface-scattering sonar system is being developed for use in a surface wave experiment, SWAPP. The new sonars will operate at 200 kHz, and have a range of 500 m, with 3-m spatial resolution. The transducers will have fan-shaped beams, similar to those used in geophysical exploration. The sonar has been interfaced to a personal computer, which greatly reduced the cost and size of the data analysis system.

Dr. Smith continues to study the interactions of surface waves and currents in the open ocean. The combined effects of wind drift and waves can cause the formation of Langmuir circulation in the top layer of the ocean. Langmuir circulation—potentially important as a mechanism for mixing wind-generated momentum throughout the mixed layer—has proven difficult to observe in the open ocean. Recent observations with 75-kHz Doppler sonar systems revealed definite evidence of Langmuir circulation at scales from three times the mixed layer depth (3×60 m) down to the resolution of the system as configured (2×20 m). The same system could simultaneously measure the surface wave field. With such surface wave and current measurements in mind, Dr. Smith is redesigning a 75-kHz system to achieve 10 m resolu-

tion, and developing a new 200-kHz system with a target resolution of about 2 m (corresponding to waves of 1.6-second period at the cutoff). As a surface-wave directional array, the sonar systems should provide quantitative, separate estimates of oppositely directed wave components in the open ocean.

Dr. William S. Hodgkiss's group focuses on underwater acoustics and signal processing. Dr. Hodgkiss continued upgrading the system control and quick look/calibration analysis software for a high-speed data-recording system (HSRS). The HSRS, designed and fabricated by MPL, is collecting data in a series of flow noise studies.

Dr. Hodgkiss also continues to work on the Swallow float array program to fabricate and take to sea a freely drifting array for measuring infrasonic acoustic ambient ocean noise in the 1–20-Hz frequency region. Although the group of Swallow floats is freely drifting, each buoy emits a localization 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.

In conjunction with Dr. Hildebrand's and Dr. Frederick H. Fisher's research groups, Dr. Hodgkiss participated in a major signal-propagation and ambient-noise experiment. His group deployed their Swallow floats as a vertical array of freely drifting VLF sensors in the vicinity of the large-aperture array deployed by Dr. Hildebrand.

Dr. Hodgkiss continues to analyze data on ambient noise that were collected by Dr. Fisher's research group during two experiments. In the first, scientists used the 48-element NORDA VEKA vertical array deployed from FLIP moored at 32°N , 124°W . In the second, they used the 32-element MPL vertical array deployed from FLIP while drifting at 32°N and 124°W , 136°W , and 150°W . Their goal is to study the time-evolving vertical directionality of ambient noise in the 100–300-Hz frequency region.

Dr. Richard K. Brienzo is analyzing a data set (taken on the Monterey Fan) for low-frequency acoustic signal propagation in thick sediments. Of interest are the acoustic attenuation characteristics of thick sediment sections as a function of frequency and depth, and the coherence between sediment-borne and water-path acoustic signals.

Graduate student David Almagor is synthesizing the reverberation time series output from a multielement or multibeam transducer array. Reverberation is the acoustic backscatter returning to a transducer from an active sonar ping and is caused by particulate matter in the volume as well as backscatter from the boundaries (surface and bottom).

Richard W. Johnson's optical systems group developed and tested a family of compact, solid-state imaging systems to automatically measure atmospheric optical and meteorological properties. Each of these devices contains a computer-controlled solid-state video system, which provides calibrated multispectral imagery suitable for extracting local image transmission and information about cloud cover. Experimental results from these systems demonstrate the effectiveness of algorithms for reliably detecting and identifying cloud-field characteristics in fully automatic mode. The automatic determination of local-sector visibilities is also being addressed. Four automatic systems have been deployed at sites in New Mexico and California. These small systems—designed for assessing key atmospheric properties—can be deployed to support experimentation and modeling. The databases derived from these devices will establish a new standard for consistent and reliable weather-related studies and analyses.

NEUROBIOLOGY

UNIT



THE NEUROBIOLOGY UNIT is part of the Marine Biomedical Program and includes four professorial laboratories with postdoctoral visitors and doctoral students.

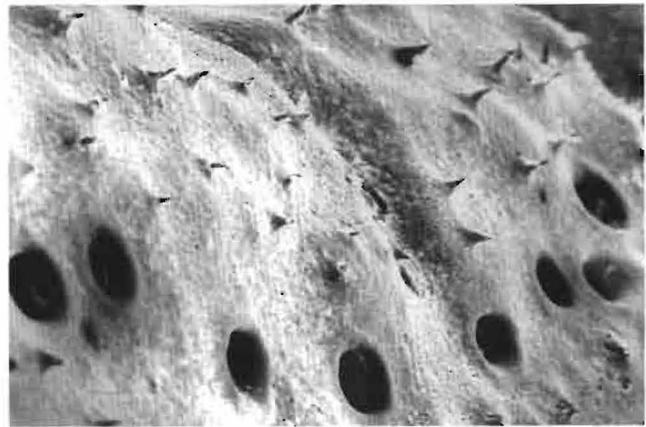
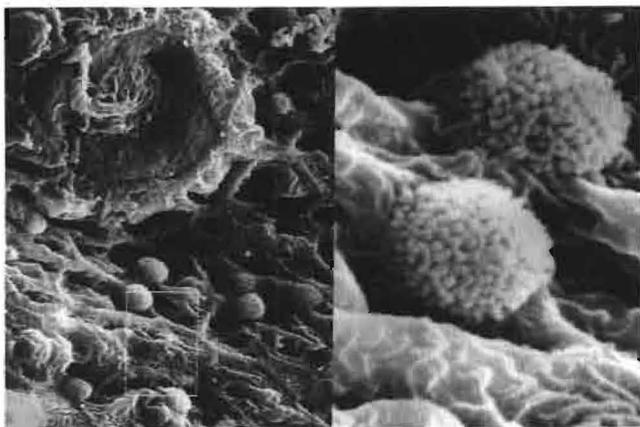
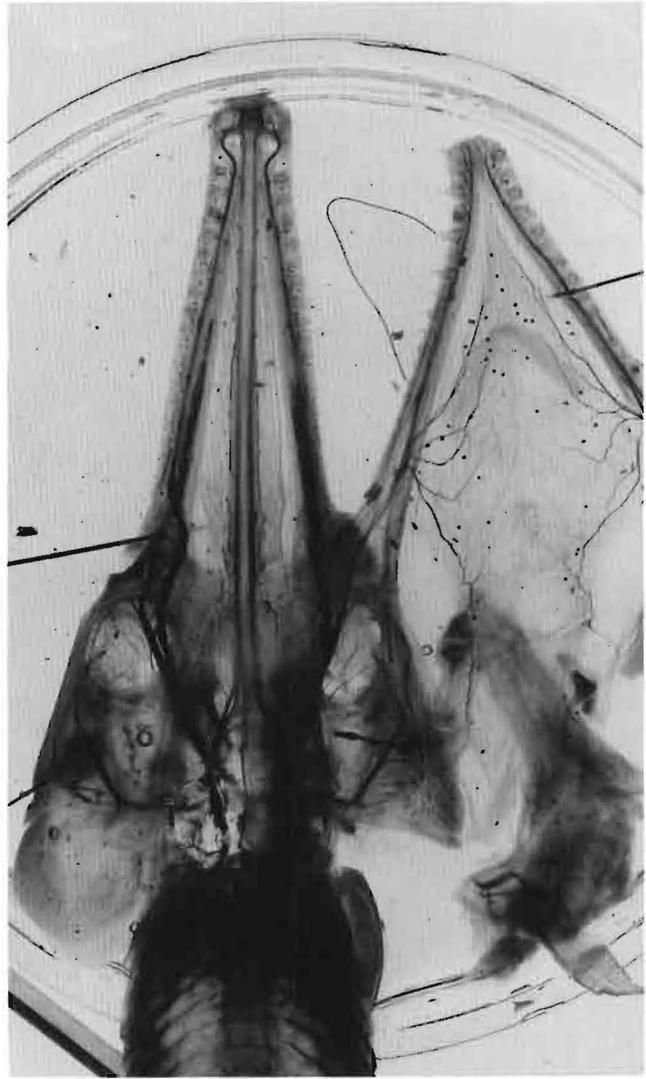
Drs. Horst Bleckmann, Oliver Weiss and Theodore H. Bullock found centers that receive and analyze input from an elasmobranch's lateral-line system of water-movement sensors. They also found some of the differences in integrative properties from the lower-level centers. Dr. Bleckmann and a visiting scientist discovered the first water-movement, lateral-line-like sense organs in cephalopods, by recording receptor potentials from a row of tiny sensors in baby cuttlefish. While studying the evolution of behavioral, neural and mental capabilities, Dr. Bullock and a colleague found a place in a ray's optic lobe that generates an electrical wave. This wave is produced about the time a flash is omitted from a series; over a wide range of flash intervals the wave occurs on schedule with the missing flash. The researchers are now comparing this to the cognitive waves known in humans noticing a novel stimulus or the absence of an expected one.

In Dr. R. Glenn Northcutt's laboratory, Dr. Richard L. Puzdrowski and graduate student Jiakun Song found that in the lateral-line systems of cyprinid and holostean fishes the body surface is mapped onto a part of the brain. Dr. Jacqueline F. Webb has found that the peripheral lateral-line system in teleosts is extremely diverse but falls into several major patterns. Dr. Northcutt is currently testing the hypothesis that much of the evolutionary diversity in lateral-line morphology is caused by changes in the timing of developmental processes.



Dr. Jiakun Song prepares a Florida gar (*Lepisosteus platyrhincus*) for electron microscopic examination.

Top left, a dorsal view of the head of a Florida gar. A colored plastic solution has been injected into the lateral-line canals to increase their visibility. *Top right*, a cleared specimen stained with Sunda black to show the innervation of the cephalic lateral-line system. *Bottom left*, a gular pit organ above several external taste buds (700x); *middle*, a higher magnification of two external taste buds (2,100x); *bottom right*, the mandibular pit line, lateral-line canal pores, and epidermal bristles (90x).

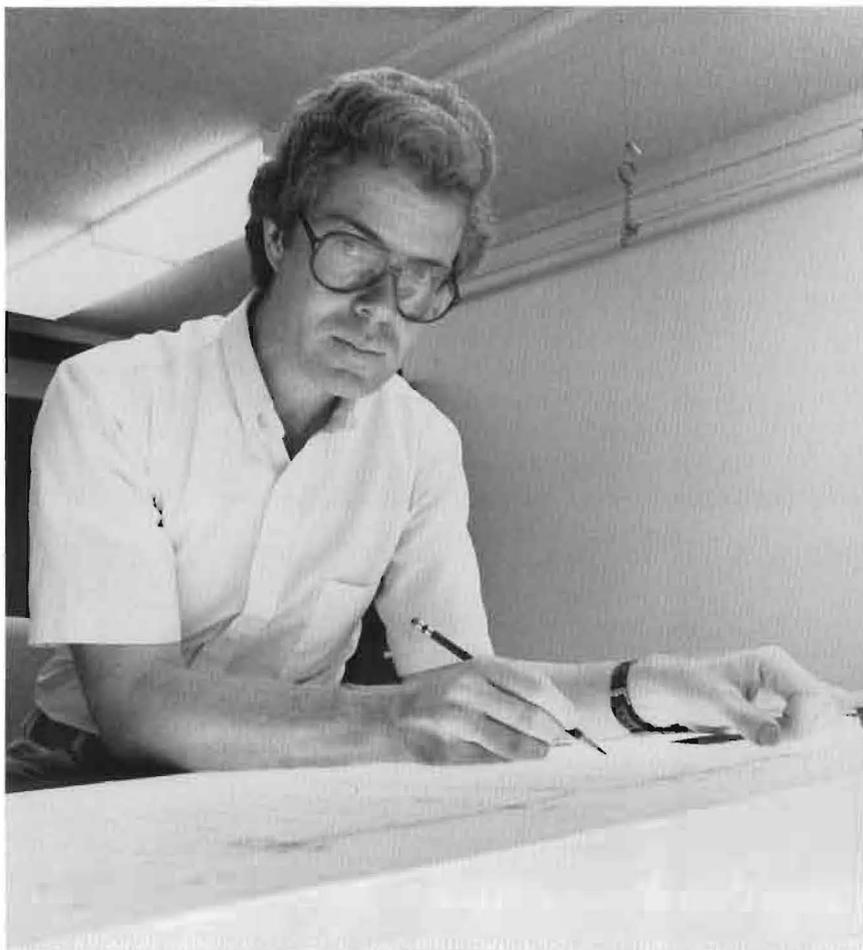


OCEAN

RESEARCH

DIVISION

Dr. James H. Swift plots a track for an Arctic cruise.



THE OCEAN RESEARCH DIVISION encompasses many aspects of marine science, from physical oceanography and climate studies to marine chemistry and electrophysiology of fishes. Here only a few selected research areas are discussed.

Circulation and Water Mass Formation in the Arctic and Greenland Seas

Dr. James H. Swift continued studying the formation and circulation of the intermediate and deep waters of the Greenland Sea and Arctic Ocean. He uses all available hydrographic and tracer data and makes new measurements when necessary. He is determining the sources of the waters' physical and chemical characteristics, and the location, strength, and structure of the circulation that carries these waters through the various ocean basins. Because he includes man-made substances in his analyses, he can view some aspects of the oceans' responses to other types of environmental forcing, such as short-term climate fluctuations.

Dr. Swift participated in the two-month cruise *Arktis IV/3* of the German ice-breaker *RV Polarstern*, which was the first shipborne survey of a major deep basin of the Arctic Ocean, the Nansen Basin. The scientists used modern oceanographic techniques, including measurements of many chemical tracers, to survey this basin north of the Barents and Kara seas. Previous oceanographic measurements in the central Arctic Ocean have been from expensive, widely separated, air-supported ice camps, with the data corresponding to single, isolated stations.

Cruise time was spent working into and then out of the Nansen Basin, which is permanently ice-covered. This station (the northernmost ever achieved by an oceanographic research vessel) was at 86.1°N, 23°E, less than 240 nautical miles from the North Pole. There were no oceanographic stations in open water, and progress was

An array is lowered into Arctic water from the German icebreaker R/V *Polarstern*.



J. H. Swift

often very slow, especially in the north, because of heavy ice conditions—surface ice as deep as 4 m, and impenetrable pressure-packed ridges of ice tens of meters thick.

During this cruise Dr. Swift measured the temperature, oxygen, and nutrients from the surface to the bottom. Other groups made conductivity-temperature-depth (CTD) measurements, analyzed water samples for total carbonate and chlorofluoromethanes (freons), and completed other physical, chemical, geological, and biological measurement programs.

These data, added to those from three other polar expeditions made by Dr. Swift, are the first multibasin, deep-ocean Arctic data set obtained with the standards and techniques used in examining the other oceans.

The data reveal boundary regimes with clearly marked, narrow features such as cores of boundary currents and intrusions of waters from peripheral regions into the interior. Early results show that various remote sources for the interior basin waters

can be identified. In the Nansen Basin, a dramatic change in the characteristics of the upper layers occurs over a very short distance at 83°N. South of this transition, the surface layers have a large component of water originating in Fram Strait, with added sea ice meltwater. North of this, the water originates east of the section and contains runoff from the Siberian rivers.

Dr. Swift is now evaluating the new *Polarstern* data, and placing the measurements in the context of existing high-quality data from other regions of the Arctic seas. This will involve collaboration with many other oceanographers.

Dr. Swift is examining interannual and seasonal variability in the Greenland Sea during 1987–1989. This study will provide CTD intercalibration required to interpret the acoustic tomographic data collected during 1988–1989 by Dr. Peter F. Worcester. Dr. Swift will oversee the data collection on twelve CTD cruises involving vessels from five countries. Dr. Swift is also using the new data to quantify the changes in the Greenland Sea water masses over a com-

plete seasonal cycle. The Greenland Sea is one of the few regions of the world ocean where sea-surface characteristics are carried into the deep waters by processes that form water masses. Quantifying and understanding these processes can improve the monitoring and modeling efforts aimed at understanding the ocean's contribution and response to climate changes.

Dr. Swift and a graduate student are examining the intermediate and deep circulation of the North Pacific Ocean in terms of 1985 expedition data. They are comparing the new data to those in the historical data files, and using a multitracer analysis technique to quantify the water mass distributions. Principal component analysis has been applied to the problem of identifying and quantifying oceanic mixing along flow paths.

Physics and Chemistry of Gas Exchange on the Ocean Surface

A new interdisciplinary research area has been established in the Ocean Research Division by Dr. Bernd Jähne. His group

studies the physics and chemistry of air-sea gas exchange.

Transport of gases between the ocean and atmosphere is controlled by a very thin layer—only 130 to 300 μm thick—at the top of the ocean. In this layer, a complicated interplay takes place between molecular diffusion of gas from the interface into the water and turbulent transport into deeper layers. For reactive gases, chemical reaction further complicates the situation.

It is not surprising that so little is known about these processes, because the thin boundary layer at a wavy ocean surface is very difficult to access experimentally. Scientists still do not know the scales and intensity of turbulence in the vicinity of this layer. The wind blowing over the ocean surface acts as the motor in two ways. First, a turbulent shear current is generated at the ocean surface. Second, the energy put into the wave field will, at least partly, be transferred to turbulent motions. This might be by wave-breaking with bubble entrainment or, less spectacularly, by “micro-scale breaking.”

Conventional measuring techniques give no insight into these processes. New instruments have been developed that allow direct access to the thin boundary layer. The controlled flux technique uses heat as a tracer to measure the local and instantaneous transfer rate across the aqueous boundary layer. For the first time, the fluctuations of the transfer process have been studied in laboratory wind/wave facilities. Scientists can use this instrument from ocean platforms and ships to measure the transfer rate directly as a function of wind speed and wave parameters. The waves will be measured with two new optical wave-measuring instruments—the reflective slope gauge and the reflective stereo slope gauge. Both instruments have been successfully used in laboratory wind/wave facilities. They are designed to operate even at high wave heights in the ocean.

Chemically reactive gases and fluorescing pH-indicators allow visualization of the

thin gas-exchange boundary layer. Simultaneously, images of waves are taken with the imaging slope gauge. Image sequences from both instruments are processed digitally. Thus the waves' influence on the boundary layer can be directly investigated. A fascinating interdisciplinary research area is unfolding that will merge chemistry, physics, and advanced image processing and will be carried out in a specially designed, small wind/wave facility.

A final focus of Dr. Jähne's group concerns satellite remote sensing of the air-sea gas exchange rate as part of the VIERS program. In cooperation with European scientists, the relationship between microwave backscatter, small-scale waves, and the air-sea gas exchange rate is being studied. The first results are encouraging. Precise satellite mapping of the gas transfer rate would be a big step forward for modeling and understanding global cycles of carbon dioxide and other gases that are crucially important to the earth's climate.

Antarctic Research Center

The Antarctic Research Center (ARC) was established in 1987, under the direction of Robert H. Whritner, to install one or two stations in the Antarctic to collect satellite data from several of the polar-orbiting spacecraft. The data collected would be used in support of aircraft flights to selected research bases throughout the continent. These data, which contain digital information about the visible and infrared characteristics of the ice, ocean, and the clouds over most of the Antarctic continent, will then be shipped to the ARC at Scripps.

The ARC's growing archive now consists of over 300 satellite passes covering parts of the Antarctic continent. Researchers can access data at the ARC and view them on a high-resolution television monitor, processing and enhancing the display to suit particular research projects. Data can also be selected from the archive and put onto standard digital tape, or reproduced photographically. Another convenient access is to

connect by phone directly to the ARC computer.

Whritner originally assisted U.S. Navy personnel in temporarily installing a military system to receive and process NOAA and USAF weather satellite data at McMurdo Station in the Antarctic. This system, which remained at McMurdo only two months, proved valuable in flight support operations. Later Scripps and a small San Diego firm jointly proposed the development of what is now the Antarctic Research Center.

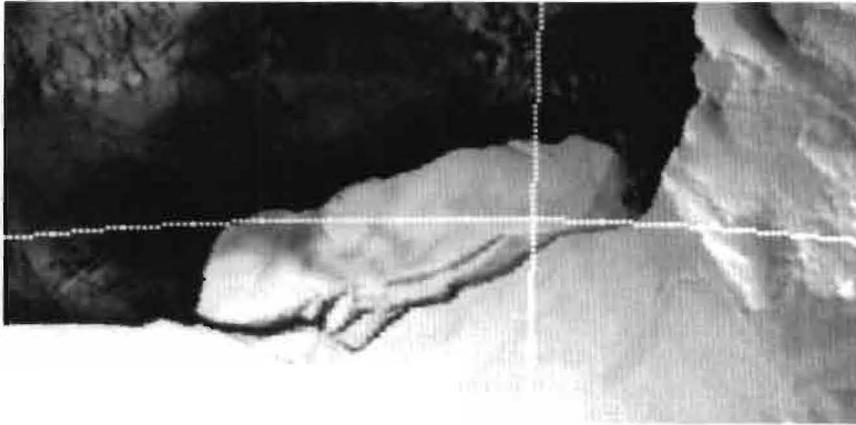
The McMurdo acquisition and processing system, which was named GODDESS (Geophysical Operational Data Display Environmental Satellite System), was placed in the Antarctic in October 1987 by Whritner and a colleague. The system is operated by U.S. Navy Antarctic Support Forces personnel.

The system is collecting NOAA polar-orbiting weather satellite data at full 1-km resolution. The data are processed on site and used in real time for operational weather, search/rescue, and flight forecasting purposes. The raw digital telemetry from all collected overpasses is also stored on magnetic tape for subsequent shipment to the Antarctic Research Center, where it is permanently archived and available for retrospective research purposes to Antarctic investigators.

Theoretical Ecology

Natural populations rise and fall, existing together in dynamic balance within variable environments. As a class of dynamic systems, ecological systems appear very complex. They occupy the so-called “middle number systems” that are difficult to treat, either statistically as an ensemble (many-body problem) or deterministically as a few-body problem. One approach to this dilemma is to try to resolve natural systems into relatively simple patterns through the choice of appropriate models. Here the idea is to find descriptive models that uncover regularities or symmetries in

Satellite photo of an iceberg that broke off from the Ross Ice Shelf in October 1987. The iceberg is now being tracked by GODOESS.



ecological data. Then these symmetries are used as physicists would—to construct better theories.

Dr. George Sugihara and Rockefeller University colleagues are investigating one class of models that involves constructing various topological representations of food webs. These models, based on graph theory and algebraic topology, are stylized portraits of the feeding relationships for a system. Applied to a large compendium of data (obtained from the literature representing 102 different marine terrestrial and freshwater systems), they have discovered several curious regularities that appear to distinguish ecological systems as a very narrow subset of mathematical possibilities. Such regularities or special elements of structure are regarded by some authors as “food web laws.” In particular, natural ecosystems appear to display certain invariant patterns of trophic connectance. Aside from their significance for constructing models of ecological systems, these patterns in trophic linkages are interesting because some can be shown in a formal sense to lead to a general, necessary, and sufficient rule guiding the dynamic assembly of ecosystems.

However attractive such general patterns may seem, they are presently based on large amounts of coarsely aggregated data or data from small subsystems. Despite the antiquity of the term *food web*, there are

presently no detailed examples of whole-system food webs. In collaboration with University of Wisconsin researchers, Dr. Sugihara is attempting to assemble the first detailed data base for the trophic structure of the whole ecosystem. This data base will be used to examine the robustness of the new generalizations about food-web structure and their applicability to whole systems.

Another class of models that may yield simple patterns in ecology is the fractal models of Benoit Mandelbrot. Fractals are based on the idea that any measure assigned to an object (e.g., the amount of length, area, volume) depends on some notion of appropriate dimensions. Thus, for example, a line has zero *area* (planar measure), whereas a plane has infinite *length* (because it would take a line of infinite length folded back on itself to fill it). Lines that are jagged and irregular may have a fractal dimension (a scaling exponent) greater than one.

Dr. Sugihara is involved in a variety of projects that concern applications of fractal scaling techniques in ecology. With the help of students, a study is being made to determine the feasibility of using fractal models to study the large-scale structure of marine phytoplankton distributions. Initial analyses of satellite images of the California Current, taken by the CZCS remote color scanner, reveal good fits to single fractal

exponents on length scales between 10 km and 10,000 km. When stable low-productivity patterns of typical years are compared with transient El Niño conditions, a correlation between fragmentation and vagility is observed. Transient El Niño years show low and high productivity regions having a patchier and more highly dissected appearance than in typical years. Such scaling between spatial pattern and persistence is characteristic of certain fractal patch extinction models.

In a similar vein, certain persistent coral colonies (e.g., *Montipora* sp.) often have simpler outlines and are less patchy than colonies of more ephemeral species (e.g., *Pocillopora* sp.). In collaboration with UC Santa Barbara scientists, a study is being proposed to determine to what extent fractal exponents computed from photographs can be used as an index of the physiological state or persistence of patches. Methods are also being developed to relate the fractal dimension of a population time series to local species extinction.

In a slightly different vein, Dr. Sugihara and students are investigating the possibility that the apparently noisy behavior of some ecological populations may be characterized by low-dimensional nonlinear dynamics, so-called “chaotic and strange attractors.” One of the central questions theoreticians must answer concerns the complexity of dynamic models: How many dimensions or degrees of freedom are required to capture the essential behavior of a system? In principle, such information may be obtainable from a time series for one component of a dynamic system. Initial analysis of the Scripps Pier temperature series suggests that this system does not have a low-dimensional attractor. Rather, the dynamics resemble a noisy limit cycle, or a sine wave with superimposed noise (noise = high-dimensional dynamics). These techniques are presently being refined for low-density time series and will be applied to a variety of biological time series.

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, recent findings of two PRL scientists and their students are presented.

Bubble Mysteries at High Pressures

Dr. Edvard A. Hemmingsen studies the physical process of spontaneous gas-phase nucleation when gas is supersaturated in water, aqueous solutions, cells, and relatively simple organisms. The nucleation events cannot be predicted quantitatively from theory. Attempts of others yielded nucleation thresholds an order of magnitude or more higher than those established and proven by experiments in Dr. Hemmingsen's laboratory. The unpredictable behavior of water probably can be traced to unexpected surface-tension properties of the water-gas interface at the sub-microscopic level. Dr. Hemmingsen is also investigating this aspect of the problem.

The process of gas-phase nucleation in liquids has many biological implications. For example, it is involved in the initial gas deposition in the swim bladders of fish

during ontogeny and in the creation of gas vesicles in many bacteria and cyanobacteria. The process is also seen in the formation of bubbles under certain conditions in invertebrates, fish, and other animals, including humans, where it can lead to decompression sickness.

Although it has previously been assumed that in vivo bubbles generally arise from gas adsorbed to hydrophobic surfaces or from microscopic gas nuclei chronically present, the research in Dr. Hemmingsen's laboratory indicates otherwise. Through studies of various invertebrates and fish, Dr. Hemmingsen and his graduate students have shown that bubbles can be nucleated spontaneously—even at low gas supersaturations—by generating momentarily large tensile forces in the aqueous fluids between closely spaced surfaces while the animals are moving. Preformed gas nuclei do not appear to contribute to the bubble formation in any of the organisms examined. Hydrophobic surfaces have proved less effective as initiation points for bubbles than others had postulated, particularly when the contacting fluids contain amphiphilic or other polar substances.

Barophilic Bacteria—New Insights from the Deep

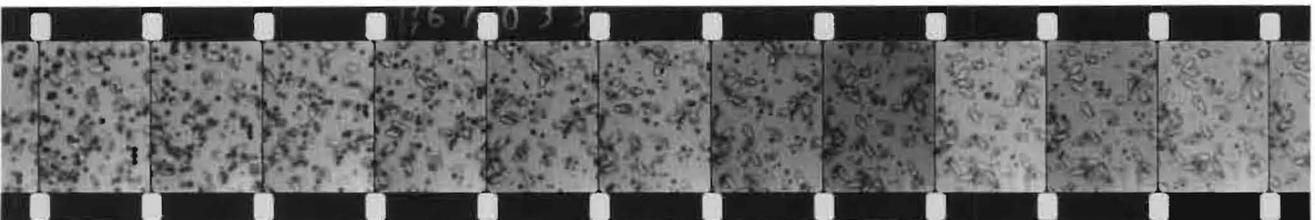
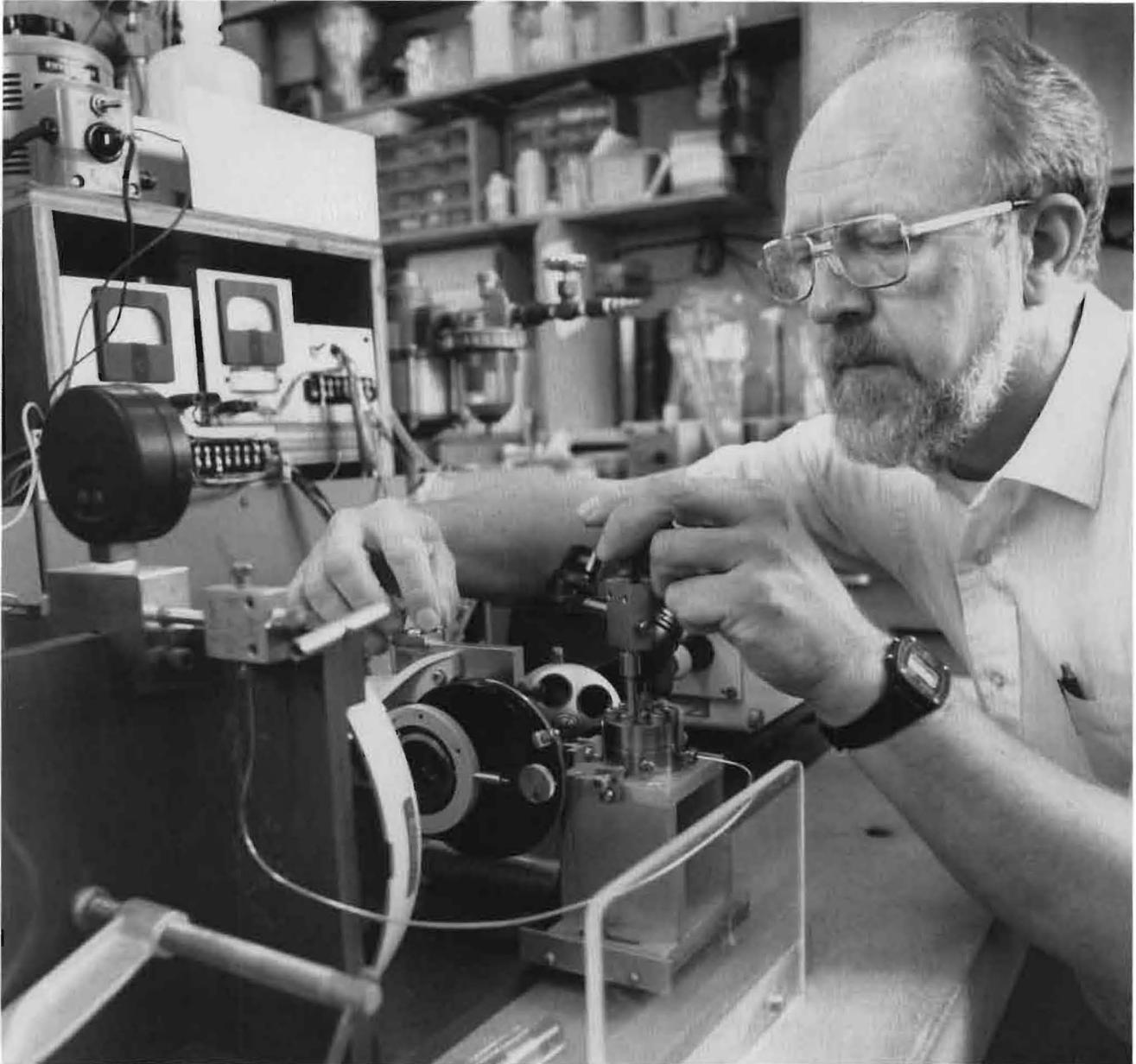
The studies of Dr. A. Aristides Yáyanos are clarifying the role of pressure in the ecology and evolution of deep-sea organisms. Physiological studies of deep-sea bacteria from depths of 2,000–10,500 m have shown that pressure may be one of the primary depth-dependent variables restricting organisms to depth zones of the sea. The

results corroborate, in a surprisingly clear way, long-known findings about the distribution of animals in the ocean. Biogeographers had shown that the distribution of animals is confined to depth ranges and, indeed, that depth-dependent endemism exists in the ocean.

Dr. Linda H. Lutz completed research on the ability of deep-sea bacteria to repair DNA damage caused by UV light or by DNA methylating agents. She found evidence that deep-sea bacteria irradiated with UV light can repair damaged DNA. By this process, called photoreactivation, the damage caused by exposure to UV light is repaired by a subsequent exposure to visible light. She also showed that several deep-sea bacterial isolates presumably contain the SOS (distress signal) DNA-repair system because they have the *recA* gene. This system, involved in the repair of DNA damaged by UV light and possibly by other agents, is widely studied in nonmarine organisms. Dr. Lutz also demonstrated that deep-sea bacteria can repair the damage caused by DNA methylating agents and that this repair—known as the adaptive response—also involves the activation of genes. Her studies set the foundation for further research on how deep-sea bacteria regulate gene function at deep ocean pressures.

Graduate student Frank J. Cynar studies the microbial aspect of the global methane cycle. He has hypothesized that the methane found near the sea surface is produced in the guts of animals. The gut environment might allow the anaerobic methanogenic bacteria to flourish. Cynar determined where the methane concentration peak is found in the Pacific Ocean near southern California, and he has cultivated methane-producing bacteria from animals captured in the depth range where seawater is supersaturated with methane. He will determine if these methanogenic bacteria thrive in the guts of animals. Ultimately, Cynar plans to model the flow of methane from its sources to its sinks in the sea surface.

Dr. Edvard A. Hemmingsen prepares for high-speed cinemicrography of bubble formation in ciliates during rapid decompression. Below is a 60-millisecond film of bubbles forming inside and outside the cells.

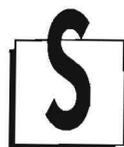


CENTER

FOR

COASTAL

STUDIES



SCIENTISTS AT THE Center for Coastal Studies (CCS), under the direction of Dr. Clinton D. Winant, focus on the processes that affect the coastal environment. Their studies include fluid-sediment interactions that transport sand along beaches and shelves; upwelling processes that bring nutrient-rich cold water to the surface along the California coast; circulation in semienclosed seas such as the Gulf of California; dynamics of the straits that connect those seas to larger ocean basins; surface gravity waves and wave-induced currents in nearshore waters; and sediment management in harbors and estuaries. Many of these projects involve field activities, and require specialized instrumentation developed in the Scripps Hydraulics Laboratory. This year one of the many CCS research areas is reviewed in depth.

The Sediment Management Group, headed by Dr. Scott A. Jenkins, is developing dissipative breakwater and seawall structures for harbors, inlets, and coastal bluffs. The initial phase of this research involved a California field study at the Camp Pendleton-Oceanside jetty, and used an ar-

ray of current meters and pressure sensors both offshore and within the jetty. The instruments, together with tracer dye studies conducted at the jetty enabled the group to determine how much wave energy the breakwater dissipates under various wave conditions. This information also led to a mathematical model of the physical mechanisms involved in breakwater-wave interactions for a conventional breakwater design.

In the laboratory, experimental breakwater sections were constructed using key elements of wave-dissipating structures found in nature—coral reefs, grooved bedrock, and natural cliff profiles. The performance of these designs was evaluated with an array of single-wire wave staffs in the wave-generating basin of the Scripps Hydraulics Laboratory.

An opportunity for a full-scale test of an experimental sea wall presented itself when the group was asked to design a sea wall for a private residence. The wall is currently in the final phase of construction, and a field study will begin this winter to evaluate its effectiveness.

The group is also reviewing work on wave overtopping of breakwaters and jet-

ties, and evaluating and refining computer programs to predict how extreme oceanographic and meteorological factors affect littoral harbor structures.

Future work will include developing technologies to efficiently pass sediment around dams. Sediment accumulation has far-reaching effects, ranging from diminished water-storage and flood-control capacities of reservoirs to accelerated beach and stream-bed erosion.

Other CCS researchers include Dr. Nancy A. Bray, who studies the thermal-haline circulation in marginal seas; Dr. Reinhard E. Flick, who investigates surf-zone turbulence and beach profiles; and Dr. Robert Guza, who observes and describes surface gravity waves and wave-induced currents in nearshore waters. Dr. Douglas L. Inman studies the fluid-sediment interactions that cause sediment transport, and the resulting bedforms—ripples, cusps, and the bars and berms characterizing the beach profile. Dr. Winant focuses on geostrophic flow along coastal margins and across sills.

Michael I. Kirk and Dr. Clinton D. Winant observe a current meter through the clear wall of the stratified flow tank at the Hydraulics Laboratory.



GEOLOGICAL

RESEARCH

DIVISION

SCIENTISTS IN THE Geological Research Division investigate a variety of ocean-related problems. Work reported on this year ranges from using varved sediments to reconstruct ocean climate, to developing a nuclear method to study phosphorus recycling.

Dr. Wolfgang H. Berger's paleoclimate group is reconstructing the climate of the California Current system, based on varved sediments of the Santa Barbara Basin. The last 50 years have been studied in great de-



Patricia S. Doyle, *opposite page*, removes teeth from a flying fish, *Hirundichthys rondeletii*, for comparison with fossil forms as part of a project to determine the biological origin of the solution-resistant, phosphatic skeletal fragments found in deep-sea sediments. *Below*, operculum raised to expose gills. Flying fish have few teeth in the mouth, but the gill arch has a well-developed pharyngeal jaw with several hundred teeth. *Bottom*, enlarged portion (40x) of the upper pharyngeal tooth plate. The distinctive trilobed teeth first entered the deep-sea sediments about 15 million years ago.



tail; microfossil data indicate a dramatic decrease in diatom and planktonic foraminifera between the periods 1950–1969 and 1970–1987. Stable isotope ratios in organic matter show synchronous shifts, which appear to be the California coastal ecosystem's response to long-term fluctuations in atmospheric and oceanic circulation of the northeast Pacific. Dr. Berger's group is also studying older sediment layers—dating back to 1500 A.D.—to accumulate a paleoclimate database. This database should provide detailed stratigraphy for El Niño events and insights about variations in biological production.

Patricia S. Doyle is using the unique shapes of fishes' teeth and scales to link present-day, open-ocean fish to their fossil record in oceanic sediments. The primary fishing grounds for the project is in the deeper (>4,000 m) world ocean. Here the fossil record of deep-sea fauna extends back about 150 million years. Because the abyssal clay deposits that underlie this part of the ocean do not ordinarily outcrop on land, this is the first glimpse into the evolutionary history of deep-sea fish populations. Identifying the fish species that produce the fossil assemblages, and identifying where in the water column they originate will increase the fossils' usefulness for investigating biostratigraphy, paleogeography, paleotemperature, and climate.

Dr. Robert L. Fisher began a four-year collaborative project to synthesize all geophysical data for the Indian Ocean and the contiguous southern oceans down to Antarctica, from 10°W to 160°E. Data on bathymetry, magnetics, deflection-of-the-vertical and satellite-derived gravity field will be analyzed, and tectonic interpretations and upgraded plate reconstructions for the area will be published. This study, under the overall direction of Dr. John G. Sclater, involves field scientists and data modelers from the United States, Europe, Africa, and Australia.

Dr. Fisher continued his collaboration with a Boston University colleague on the

petrological-geochemical analysis of igneous rock samples from the very deep Tonga and Philippine trenches. Similar work is under way to evaluate the structural implications of collections from the Challenger Deep. Dr. Fisher collaborated with Dr. James H. Natland and others on petrological-geochemical analysis of Scripps's extensive dredged collections of tholeiitic glasses and volcanics, and mafic-ultramafic plutonic rocks from the Central, Southeast, and Southwest Indian ridges. The data provided ground-truth input for models of magma generation and mixing in the mantle, of processes of emplacement and exposure in the spreading ridge segments and cross-cutting fracture zones, and for the recognition of significant geochemical differences or similarities between regions or entire ocean basins.

Dr. William R. Riedel is investigating how artificial intelligence programing can be applied to microfossil investigations. He and his colleagues are developing programs to help identify the fossils, assign ages, and interpret paleoenvironmental conditions. The database being assembled for this purpose comprises information on radiolarians and sediment types collected from the Cenozoic World Ocean during the Deep Sea Drilling Project.

Annika Sanfilippo is studying the evolution of radiolarians in deep-sea sediments recovered by the Deep Sea Drilling and Ocean Drilling projects. She supplements the data with land-based sequences for greater resolution near the Eocene/Oligocene boundary (samples from Barbados, West Indies) and in the Paleocene (samples from SW France). The problem of identifying ancestral forms to reconstruct phylogenies based on fossil evidence is a complex one because of the uncertainty of how representative the fossil record might be. However, a number of lineages have been revealed. The lineages are essential for constructing a natural taxonomy, for studying stratigraphy, and for elucidating species diversity and evolutionary patterns among fossil and living Radiolaria.

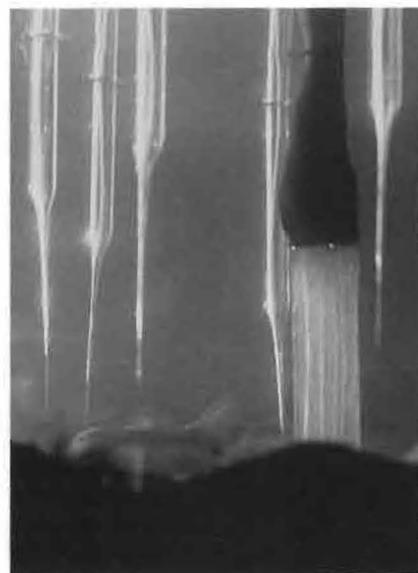
RESEARCH ACTIVITIES

Dr. Devendra Lal and colleagues developed a new nuclear method to study phosphorus recycling in the upper ocean. This method uses the twin radiotracers ^{32}P (half-life, 14.3 days) and ^{33}P (half-life 25.3 days), which are produced by interactions of cosmic rays in the earth's atmosphere and in the oceans. These nuclides in dissolved inorganic/organic phosphorus and in particulate organic phosphorous pools are useful for studying P cycling on timescales compatible with those involved in biogeochemical processes and in trophic interactions within the food web.

Dr. Clare E. Reimers and her group continued studying the oxidation of organic matter and the early diagenesis that occurs near the sediment-water interface. Factors producing variable patterns in pore-water oxygen gradients and consumption rates were investigated on both small and large spatial scales. The group used Woods Hole's research submersible *Alvin* to deploy repeatedly a microelectrode-based instrument—called the *in situ* microprofiler—on the seafloor of the Santa Catalina Basin. The microprofiler was also deployed along two E-W transects of the central California continental slope, where box cores were also made. This work demonstrates that oxic respiration consumes nearly all of the organic carbon input to the seafloor within the first 1-2 cm of sediment, except at locations in the heart of the oxygen minimum zone.

Dr. Reimers also began a study of phosphorus cycling and authigenic mineral formation within the laminated sediments of the Santa Barbara Basin. This research focuses on the roles that bacterial and redox-sensitive equilibria play in phosphate-mineral precipitation.

Dr. Clare E. Reimers constructs an oxygen microelectrode for the *in situ* microprofiler. Bottom left, the instrument profiles ocean sediments at 3345 m. This photo was taken with a stereo camera mounted on the deployment free vehicle. Bottom right, a close-up of the instrument's sensors.



CALIFORNIA

SPACE

INSTITUTE



THE CALIFORNIA SPACE INSTITUTE (Cal Space) is a universitywide unit, head-

quartered at Scripps, which supports and conducts space-related research. Cal Space's strongest ties to Scripps are in the field of satellite remote sensing of the ocean atmosphere. In addition to its research for the institute, Cal Space operates a small universitywide grant program open to researchers in astrophysics, space science, satellite remote sensing, and space technology. Each year Scripps scientists have successfully competed for these grants, which support students or are used as program seed money.

Cal Space, under the direction of Dr. James Arnold, has made advances in automation and robotics. As NASA's space station project moves forward, Cal Space scientists are pursuing a variety of research activities.

Cal Space researchers discovered early on that there is a similarity between the problems faced in space and those under the sea. Thus Cal Space scientists are working with Marine Physical Laboratory investigators who have research interests in undersea robotics and teleoperation.

Dr. Mahmoud Tarokh tests a new control algorithm for the robot arm.



Dr. Mahmoud Tarokh is using improved control algorithms and sensors to increase the dexterity and precision of robot arm movements. Philippe E. Collard is studying the application of ADA language to automation and robotics. In work with Cal Space's remote sensing group, Collard is developing computer-based procedures for classifying cloud types in satellite images.

Dr. Lucy-Ann McFadden focuses on the remote use and control of complex scientific instruments in space. Her work may apply to problems in the ocean-atmosphere system.

The earth remote sensing group, directed by Dr. Catherine H. Gautier, extended its involvement in earth science and global change studies, participating in-

terdisciplinary research programs such as the Tropical Ocean Global Atmosphere and the International Satellite Cloud Climatology programs. The group is interested in long-term variation of the earth's energy and water cycles and their impact on the planet's ecology. Satellite observations of the earth's atmosphere and surface (land and ocean) are used to investigate clouds' effects on radiative energy and water budget interactions between the atmosphere and oceans.

Using geostationary satellite observations and radiative transfer models, Cal Space scientists can accurately compute surface solar and longwave irradiances—the driving force behind atmospheric and oceanic circulations. Drs. Gautier and Robert J. Frouin are studying the interannual variability of surface solar radiation over the tropical Pacific Ocean to clarify its impact on climate processes, particularly the El Niño/Southern Oscillation—one of the most intriguing climatological phenomena in recent years. They are investigating and quantifying the role that reduced solar radiation in the central and eastern Tropical Pacific Ocean (associated with the displacement of large-scale convective systems) may play in decreasing warm sea-surface temperatures.

Another Cal Space project focuses on the Indian summer monsoon and the dramatic heat and moisture exchanges across the ocean-atmosphere interface in conjunction with the monsoon's abrupt onset. Until recently, such studies relied solely on ships for collecting measurements and were thus limited in describing the monsoon's large, rapid, and spatially extended geophysical processes. An ensemble of satellite observations is used to quantify the air-sea heat and moisture exchanges as well as the radiative, moisture, and water (precipitation) changes occurring in the atmosphere.

Several Cal Space scientists are participating in Scripps's University Research Initiative program to design realistic models of the North Pacific Ocean, with emphasis

on the California Current. Such models assimilate remotely sensed and in situ-measured geophysical forces like surface winds and heat fluxes to provide forecasts for climate dynamic studies and seagoing activities. Geoffrey K. Vallis and Alejeandro Pares-Sierra have built quasi-geostrophic models of varying resolution of the North Pacific Ocean and California Current. Vallis and Pares-Sierra also developed a high-resolution, primitive equation model, which depicts the California Current's upper-layer thickness in a one-layer reduced-gravity model. These models test important hypotheses about how El Niño events influence California coastal sea level, particularly whether sea-level variations result from northward propagation of coastal oceanic Kelvin waves or from atmospheric teleconnections. Currently under development is a multilayered extension of the reduced-gravity model, which incorporates topography and an efficient method for determining a fluid's barotropic component.

In the same program Drs. Gautier and John J. Bates, and Collard supplied the models with satellite-derived products of atmospheric forcings (heat and momentum) of upper ocean circulation and heat content. The researchers are devising methods to analyze multisensor satellite observations to account for spatial and temporal information. To do this they created automated techniques to compute the displacement of surface thermal features from consecutive infrared images of the ocean surface.

Dr. David P. Rogers measures and models the evolution of the marine atmospheric boundary layer. In conjunction with airborne studies carried out during the Frontal Air-Sea Interaction Experiment, he is developing a numerical model to investigate how cloud fields respond to ocean temperature fronts. This study indicates that the boundary layer is strongly influenced by temperature discontinuities in the ocean, particularly through the development of internal boundary layers and

cloud/subcloud coupling. Collaboration with other Cal Space researchers will improve remote sensing of marine boundary layer phenomena.

As part of the International Land Surface Climatology Program and in an effort to better understand interactions between the atmosphere and land, Cal Space researchers have been studying the surface radiative processes occurring over small spatial scales (1 to 10 km). Using satellite observations, they estimated the different parameters characterizing the surface radiation budget (downwelling and upwelling solar radiation, surface albedo, downwelling and upwelling longwave radiation, and surface emissivity) in clear conditions. They then validated these estimates with in situ measurements made in 1987 during an intensive observation experiment in Kansas. The analyses will further the quantitative interpretation of satellite observations from high-resolution (10–30 m) sensors on satellites devoted to land observations, such as Landsat and Spot.

Cal Space scientists also study biological primary ocean productivity on a regional and global scale. To this end, Drs. David W. Lingner and Gautier are developing a method to estimate marine primary productivity from space by using satellite measurements of environmentally forced parameters. The model incorporates (1) plant biomass, inferred from Coastal Zone Color Scanner chlorophyll images; (2) sea-surface temperature, derived from the Advanced Very High Resolution Radiometer; and (3) incident photosynthetically available radiation, estimated from the Visible and Infrared Spin Scan Radiometer. To verify and improve upon the biological model, the satellite-derived productivity estimates are compared against surface-based (ship, buoy, and mooring) data.

INSTITUTE OF
GEOPHYSICS
AND PLANETARY
PHYSICS



THE SAN DIEGO branch of the University of California systemwide 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 research programs on very different topics are discussed.

On the ice sheet in Greenland, Dr. Mark A. Zumberge reads a gravity meter.



J. M. Stevenson

**RESEARCH
ACTIVITIES**

**Graduate student Glenn S. Sasagawa assembles
an absolute gravity meter before testing.**



Determination of the Newtonian Gravitational Constant

Scientists from several U.S. institutions have gathered at IGPP to address recent global measurements that suggest that Newton's law of gravity may break down at distances in the range of a few tens of meters to a few tens of kilometers. Newton's law predicts the attraction between any pair of objects separated by a particular distance. Some physicists attribute the anomalous behavior to a new force in nature. Classical geophysical survey techniques are being applied to test the radically new theories of physics.

Scientists from Scripps and Los Alamos National Laboratory make up a planning group, sponsored by IGPP, to study how the earth's gravity varies with height in an environment where the density of nearby material is well known. Others have made measurements in mines and boreholes in the ground but lacked knowledge of the mass of surrounding rock. The IGPP study group, which eventually included Scripps scientists and researchers from many other institutions, planned two experiments that involve measuring the variation of gravity with depth in water. The first experiment was performed in frozen water (on the ice cap covering Greenland); the other is being done in the Pacific Ocean near Hawaii.

The idea behind these experiments stems from nineteenth-century work by Sir George Airy, and recent work by Dr. Frank Stacey, University of Queensland, Australia. The universal gravitational constant, G , in Newton's law of gravity can be determined by measuring the strength of gravity at various depths in a mine. Two terms govern the variation of gravity as an observer descends from the earth's surface. The first is the attraction of the earth's bulk, including the globe as a whole and local structures like mountains and subterranean rock formations. The second term comes from the direction reversal of pull by the material that immediately surrounds the descending

observer as mass moves from below him to above him. The first term can be calculated when there is an adequate knowledge of the earth's shape and the local topography. The second term requires precise information on the density of the material through which the observer moves. Therein lies the advantage of performing the experiment in water rather than rock. The density of seawater and its variation with depth, temperature, and salinity is widely known. The ice in the great ice sheets is amazingly pure, so its density is readily predicted. The problem then becomes separating the two terms.

In the Greenland experiment, which was performed during the summer of 1987, gravity measurements were made in a borehole previously drilled 1,700 m into the ice sheet. A radar survey and a series of gravity measurements along the surface of the ice sheet were made to model the effects of subice rock. Analysis of the data is currently under way.

Because of ship motion and currents at depth, measurements of gravity below the ocean surface are far from routine. New gravity meters are being perfected for use in this ever-moving environment. The great depth of the ocean, the ability of oceanographers to create maps of undersea topography, the readily available gravity information contained in the shape of the ocean surface, and the high precision with which the density of seawater can be determined provide the right combination for an unusually accurate determination of the Newtonian gravitational constant. The gravity measurements begun on the ocean bottom during the summer of 1988 may yield the best test ever of Newton's law.

Measuring the Geomagnetic Field at the Core-Mantle Boundary

Magnetic north in London has swung 36° in two centuries, and in the last century the strength of the earth's magnetic dipole has dropped by five percent. These large and rapid changes are produced by flow in the

earth's molten iron core, which acts as a self-regenerative electrical fluid dynamo (molten iron is not magnetic). The flow and the dynamo could be studied if the geomagnetic field \mathbf{B} at the core-mantle boundary (CMB) could be measured. For this purpose, the available data are measurements of \mathbf{B} on and above the earth's surface. Even satellite measurements provide only finite data, and there are infinite dimensions in the model space X of all possible magnetic fields \mathbf{B} produced outside the core by electric currents within. Hence, finding \mathbf{B} at the CMB from surface and satellite data requires that scientists solve a finite number of equations for an infinite number of unknowns. Moreover, even if the surface data available were infinite, none would be perfectly accurate. Dr. Jacques-Salomon Hadamard showed that arbitrarily small errors in the surface data propagate down to large errors at the CMB if the horizontal wavelength of the errors is short enough.

Geomagneticians resolve these difficulties by incorporating prior information into the data analysis. The magnetic energy at short horizontal wavelengths cannot be so great that more ohmic heating in the core is required for its generation than is observed to diffuse out of the earth's surface. And the magnetic energy cannot be so great that its rest mass exceeds the astronomically measured mass of the earth. Both heat flow and magnetic rest mass provide "prior quadratic bounds" on the correct magnetic field \mathbf{B} . That is, each provides a number, q , and a homogeneous, positive, quadratic polynomial $Q(\mathbf{x})$ defined for all \mathbf{x} in X , such that even without the data the observer is confident that the true field \mathbf{B} satisfies $Q(\mathbf{B}) \leq q$.

In the last decade scientists have disagreed on how to incorporate such prior quadratic bounds into magnetic data processing. The currently favored techniques—Bayesian inference (BI) and stochastic inversion (SI)—require a probability distribution p_x on X , which describes

where the observer thinks the correct \mathbf{B} is likely to be in X if the scientist has not yet seen the data. Then BI and SI are two standard statistical theories that tell the observer how the data's new information should lead to modifying the prior p_x . The difficulty with BI and SI lies in choosing a prior p_x that conveys roughly the same information contained in the belief that $Q(\mathbf{x}) \leq q$. The "hard bound" $Q(\mathbf{B}) \leq q$ must be "softened" to a probability distribution p_x . Recently Dr. George E. Backus found a rigorous proof that this cannot be done. Softening a hard quadratic bound inevitably adds spurious information about the earth, information and structure implied neither by the data nor the bound $Q(\mathbf{B}) \leq q$. Therefore, if the prior information really is a hard quadratic bound, neither BI nor SI is an acceptable technique for data reduction.

Fortunately there is an alternative technique for dealing directly with hard bounds—confidence set inference (CSI); presoftening is unnecessary. CSI, based on Neyman's now classical work on confidence intervals, gives about the same results as BI and SI, but the error bounds are larger in CSI. (In compensation, they are rationally defensible.) Both BI and SI have overestimated the horizontal resolution available on the CMB. The circle of confusion for \mathbf{B} there has a diameter of about 25° rather than 16° . (In SI, BI, and CSI the primary cause for inaccuracy and poor resolution at the CMB is the unknown crustal magnetization.) CSI requires more computing than BI or SI, and depends heavily on efficient use of the accumulated prior information about the earth. Work on both these problems continues.

INSTITUTE

OF

MARINE

RESOURCES

DURING 1988 Dr. William H. Fenical was appointed acting director of the universitywide Institute of Marine Resources (IMR), which is headquartered at Scripps. IMR oversees several research programs at Scripps and at Davis. It also administers the California Sea Grant College Program, headquartered at Scripps. Highlighted this year are the California Sea Grant Program and the activities of two members of the Scripps-based Food Chain Research Group.

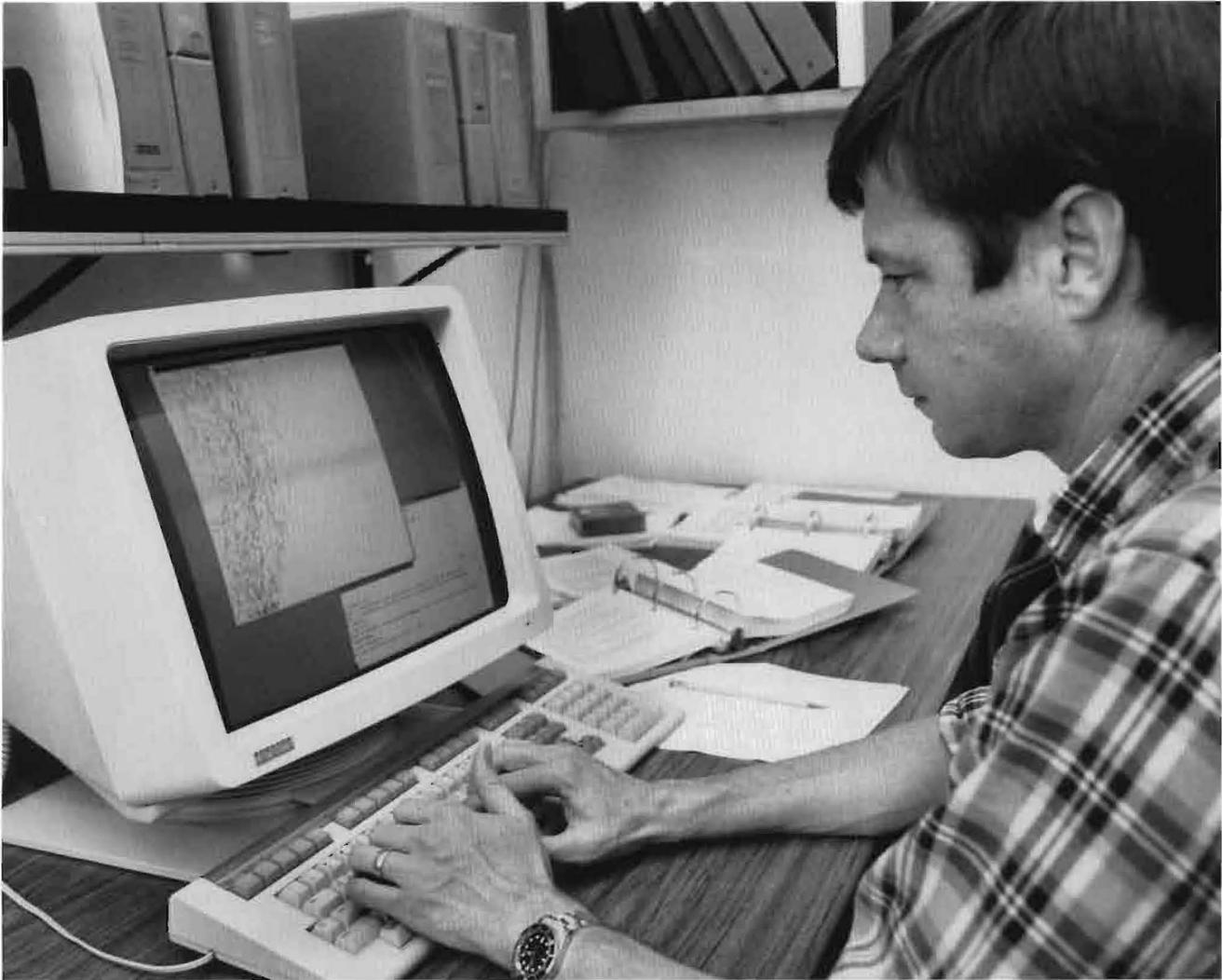
Food Chain Research Group

The Food Chain Research Group (FCRG) is an interdisciplinary program investigating the production, transformation, and loss of organic material in the ocean over a spectrum of scales from molecular to global. Working on the smaller scales of physical and chemical processes, Dr. George A. Jackson uses mathematical models and computer simulations to clarify how particle size, leakage rate, and water motion affect interactions between organisms. Dr. Jackson's idealized system involves a solitary algal cell, which leaks a chemical cue to the water, and a bacterium that tries to find and stay near or attach to the alga. The idealized bacterium incorporates biological responses and acts as a surrogate for other microscopic organisms. He sees a cutoff size of about $5 \mu\text{m}$ diameter, below

which a cell is not likely to be detected by chemical means. Because of this size limitation for chemical detection, small cells interact differently than larger cells. This occurs because the interactions involve different sensory exchanges. For example, copepods graze on algal cells by sensing the chemical environment around them. The fact that many copepods do not eat cells smaller than about $5\text{--}10 \mu\text{m}$, but other larger animals, such as salps, do suggests that this is caused by an inability to sense the small cells. Such size-based constraints can be important in structuring marine food webs.

Physical processes on a larger scale also help determine the nature of the kelp bed ecosystem. This system depends on surrounding waters to supply nutrients to support kelp growth, larvae to provide the new generations of fishes and other animals, and food to feed planktivorous fish. Dr. Jackson has been studying the currents that move these materials in and out of the kelp. The high drag of the kelp dramatically slows water movement into the bed, as well as the subsequent distribution of the water and its material within the bed. He is trying to predict the distribution of organisms in the kelp by studying their behavioral responses to the kelp system and its currents. Results suggest that many of the more active waterborne materials may not reach

Dr. George A. Jackson uses a computer to simulate bacterial motion around a falling particle.



more than 100–200 m into the kelp bed. A large kelp bed, such as that at Point Loma off San Diego, may be 7 km along the shore and 1 km wide. The area within 100 m of an edge of such a kelp bed is a small fraction of the total bed. If the recruitment of benthic animals from planktonic larvae occurs mostly in the outer regions, then the ecological interactions in the interior will be much different. Anecdotal evidence provided by sea urchin collectors indicates that sea urchins recruit mainly within 100 m of the outer edge. Be-

cause grazing by sea urchins is so important in kelp ecosystems, this is one example of how the decrease of currents in a kelp bed can influence the ecosystem.

Organisms control the distribution of many chemical elements in the sea, including nitrogen and carbon. Their concentrations are influenced by the presence of organic carbon compounds. Presently there is confusion about the concentrations of dissolved organic carbon (DOC) and nitrogen (DON) because new analytical techniques have measured different concentra-

tions. Drs. Jackson and Peter M. Williams have been analyzing the interactions between dissolved organic compounds and other chemical cycles, including that of oxygen. Whatever the actual concentrations of DOC and DON, they must be consistent with the concentrations of other elements (such as oxygen), and their distributions must be consistent with those of other processes and chemical forms, including the sinking of particles containing carbon and nitrogen.

Other members of the FCRG are in-

RESEARCH ACTIVITIES

Involved with national and international research programs focused on global problems—such as the increase in atmospheric carbon dioxide and large-scale climate changes. The ocean plays a large role in climate change. It is a sink for some of the atmospheric carbon dioxide produced by burning fossil fuels; it is also a source of methane, dimethyl sulfide, and other volatile substances important to the heat budget of the atmosphere and the earth's surface.

Several members of the FCRG are studying such large-scale ocean biochemical cycles in the context of the national Global Ocean Flux Study (GOFS). Dr. Williams is involved in joint U.S.-Japan GOFS studies of dissolved organic matter, at present a contentious aspect of the ocean carbon cycle. Drs. Farooq Azam and Jackson serve on GOFS working groups on upper ocean processes and modeling.

Dr. Richard W. Eppley will participate in a study of the spring plankton bloom in the North Atlantic aboard R/V *Meteor*. Scientists on the cruise will measure the fraction of primary production that will be exported from the surface layer to the ocean's interior. Biologists call this fraction "new production," contrasting it with the fraction of primary production that is recycled within the surface waters.

Current estimates of global new production are on the order of 5 gigatons of carbon per year (5×10^9 tons/year). This is the same magnitude as the input of carbon dioxide to the atmosphere from the burning of fossil fuels. Small changes in the rate of oceanic new production may thus be important for carbon dioxide's rate of transport to the interior ocean, and for its buildup in the atmosphere. Most new production takes place where nitrate is brought to the surface—in regions of deep winter mixing in temperate and polar latitudes, and in regions of upwelling. The latter include the equatorial Pacific and the eastern boundary currents, including the California Current. Primary production

Currents within a kelp bed differ with position. Map and aerial photos show the positions of four stations separated from adjacent stations by about 250 m. The graphs show currents flowing alongshore, with the lower sections representing currents farther inside the kelp bed. The velocity decreases over short distances because of the kelp drag.

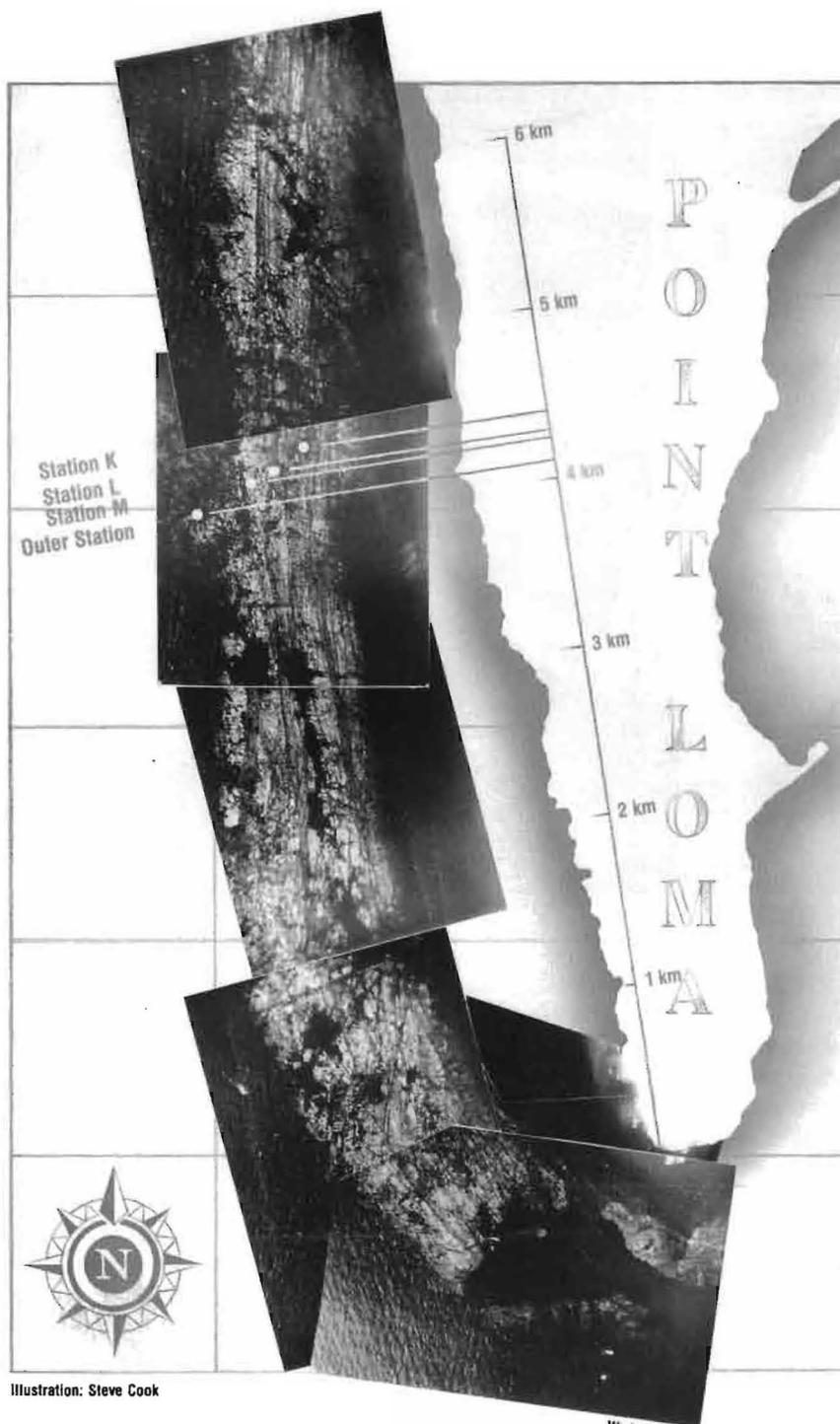


Illustration: Steve Cook

W. J. North

shows large interannual variability in such regions, some of it related to El Niño type events. New production may be equally or even more sensitive to such climate-related changes. The plankton processes, their physical forcing, and climate are interrelated in scenarios of global change. Individual oceanographers in multidisciplinary programs such as GOFS find many challenging problems to be addressed.

California Sea Grant College Program

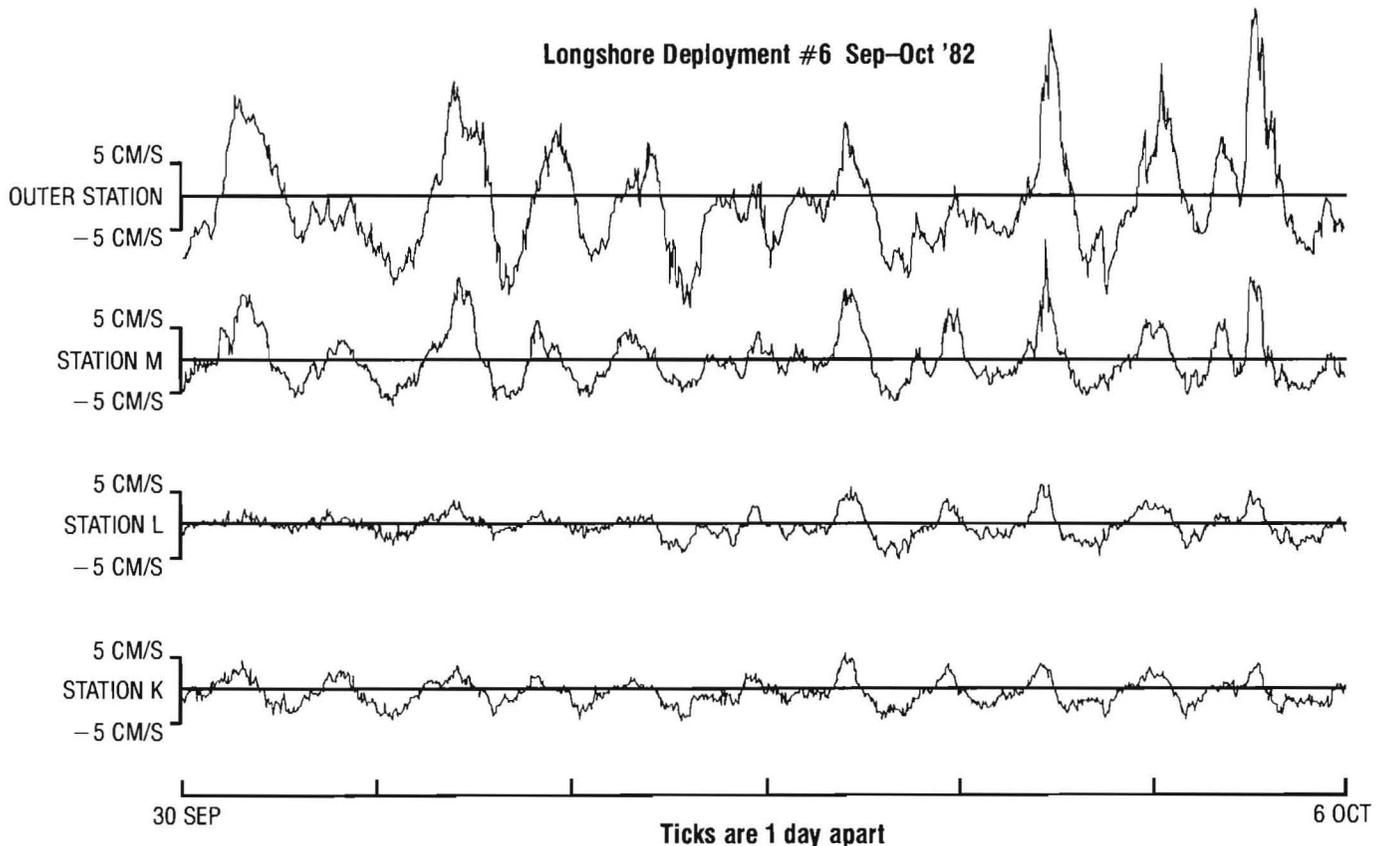
The California Sea Grant College Program, directed by Dr. James J. Sullivan, is a systemwide program of the University of California administered by the Institute of Marine Resources and headquartered at Scripps Institution of Oceanography. California Sea Grant, part of the National Sea

Grant College Program, is a partnership between the federal government and public universities in the coastal and Great Lakes states. The Sea Grant program promotes development, conservation, and management of marine resources through programs of research and education.

Modeled loosely on the Land Grant concept, Sea Grant supports fundamental research projects that have potential social benefit. In 1987–1988, California Sea Grant sponsored research projects at Scripps on such topics as nearshore sediment transport, atmospheric forcing of coastal sea level, halibut metabolism, Pacific whiting prey, and potential new pharmaceutical agents from marine organisms. In addition, with Sea Grant support, Scripps researchers worked to develop an acoustic

Doppler system for directional wave measurements, a hybrid sonar system that will improve methods of surveying river channels and other shallow bodies of water, and an instrument to profile the thermal flow of “black smoker” vents to determine their potential for providing thermal power. As part of these projects, Sea Grant supported 10 Scripps students.

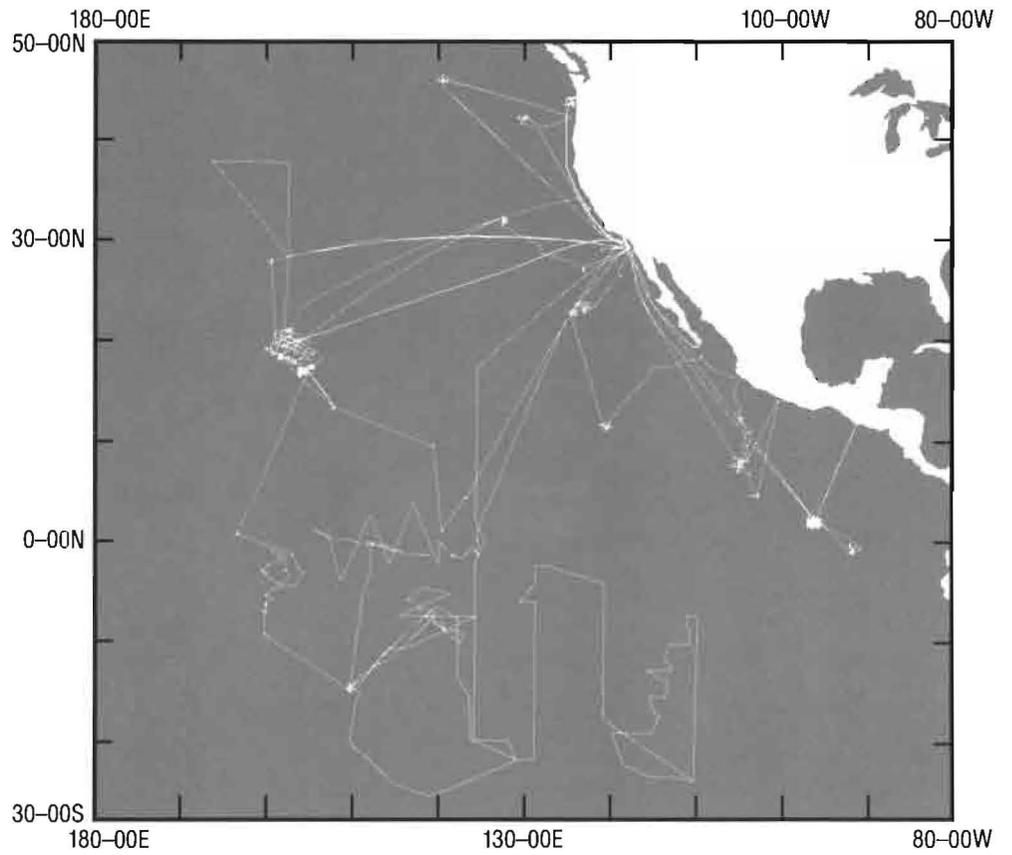
Because of Sea Grant's mandate to increase the social benefits of science, its researchers have historically sought to create stronger links among the university, industry, and government. This linking function was the focus of research by Dr. Sullivan, who spent a year in Japan studying how the Japanese target their efforts in research and development to areas believed important to their nation's economy.





SEAGOING OPERATIONS

SHIP CRUISE TRACKS FOR FISCAL 1988



R/V Robert Gordon Sproul

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
07/01-07/10/87		Southern California coast	Shark studies	San Diego	C. Lai	L. Zimm
07/13-07/16/87		Southern California coast	Equipment testing	San Diego	C. Reimers	T. Beattie
07/20-07/22/87		Southern California coast	Biology	San Diego	D. Lal	T. Beattie
07/23-07/25/87		Santa Barbara Basin	Biology	San Diego	C. Cary	T. Beattie
08/12-08/18/87		Southern California coast	Equipment testing	San Diego	P. Niiler	T. Beattie
08/19/87		San Diego Trough	Equipment testing	San Diego	R. Williams	T. Beattie
08/23-08/29/87		Southern California coast	Food chain biology	San Diego	W. Balch	T. Beattie
09/02-09/14/87		Southern California coast	Physical oceanography	San Diego	J. Simpson	T. Beattie
09/15-09/22/87		San Diego Trough	Acoustics studies	San Diego	W. Hodgkiss	T. Beattie
09/26-09/28/87		Southern California coast	Geochemistry	San Diego	D. Lal	T. Beattie
09/29-10/01/87		Southern California coast	Benthic biology	San Diego	A. Yayanos	T. Beattie
10/02-10/06/87		Southern California coast	Biology	San Diego	T. Klinger	T. Beattie
11/01-11/08/87		Southern California coast	Student cruise	San Diego	K. Smith	T. Beattie
11/09/87		Southern California coast	Equipment testing	San Diego	R. Davis	T. Beattie
02/20/88		Southern California coast	Student cruise	San Diego	R. Rosenblatt	T. Beattie
02/22-02/27/88		Southern California coast	Biology	San Diego	C. Reimers	T. Beattie
03/30-04/03/88		Santa Cruz Channel	Equipment testing	San Diego	C. Cox	T. Beattie
04/05-04/09/88		Santa Monica Basin	Biology	Los Angeles	N. Kachel (UW)	T. Beattie
04/09-04/12/88		Santa Monica Basin	Biology	San Diego	N. Kachel (UW)	T. Beattie
04/19-04/22/88		Southern California coast	Biology	San Diego	A. Yayanos	T. Beattie
04/26-05/05/88		Southern California coast	Physical oceanography	San Diego	J. Simpson	T. Beattie
05/13-05/23/88		Santa Cruz Basin	Tracer studies	San Diego	J. Ledwell (LDGO)	T. Beattie
05/24-05/30/88		31°30'N, 121°30'W	Equipment recovery	San Diego	J. Orcutt/ C. Cox	T. Beattie
06/02-06/17/88		Santa Cruz Basin	Tracer studies	San Diego	J. Ledwell	T. Beattie
06/20-06/25/88		Santa Barbara Basin	Geochemical studies	San Diego	C. Reimers	T. Beattie
06/27-07/01/88		Southern California Bight	Food chain biology	San Diego	B. Ward	T. Beattie

TOTAL DISTANCE TRAVELED: 12,854 nautical miles OPERATING DAYS: 136

R/V Melville

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
07/23-08/13/87		44°20'N, 129°45'W	Deep Tow and thruster tests	Newport	F. Spiess/ J. Delaney (UW)	C. Johnson
08/16-08/29/87		48°N, 139°W	Mooring deployment	San Diego	R. Davis	C. Johnson
09/16-10/19/87	Helios I	135°W between 25°N and 25°S	Geochemistry	Papeete	H. Craig/ R. Sheltema (WHOI)	R. Haines
10/24-11/24/87	Helios II	5°-25°S, 110°-140°W	Geochemistry	Easter Island	S. Riser (UW)	A. Arsenault
11/26-12/18/87	Helios III	5°-25°S, 110°-140°W	Geochemistry	Easter Island	S. Riser (UW)	C. Johnson
12/20/87-01/05/88	Helios IV		Transit	San Diego		C. Johnson
01/26/88		Off San Diego coast	Sea trials	San Diego		C. Johnson
03/06-03/18/88	CIRCUS II	33°-40°N, 119°-35°W	Geodesy and Deep Tow	San Diego	F. Spiess/ J. Hildebrand	C. Johnson
03/23-04/01/88	Galapagos '88 I		Transit	Puerto Quetzal		C. Johnson
04/04-04/23/88	Galapagos '88 II	Galapagos vents	Biology with <i>Alvin</i>	Galapagos	J. Childress (UCSB)	C. Johnson
04/23-05/14/88	Galapagos '88 III	Galapagos vents	Biology with <i>Alvin</i>	San Diego	J. Childress (UCSB)	C. Johnson
05/23-05/25/88		San Diego coast	Equipment testing	San Diego	P. Worcester	C. Johnson
06/01-06/05/88			Transit	Astoria		C. Johnson
06/06-06/15/88		Endeavor Ridge	Hydrothermal tracers	Seattle	M. Lilley (UW)	C. Johnson
06/17-07/07/88		47°N, 37°W	Physical oceanography	Newport	C. Eriksen	C. Johnson

TOTAL DISTANCE TRAVELED: 31,718.90 nautical miles OPERATING DAYS: 256

**SEAGOING
OPERATIONS**

R/N New Horizon

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
07/12-08/03/87	Bempex I	Honolulu	Biology	Honolulu	J. Childress (UCSB)	P. Munsch
08/06-08/18/87	Bempex II	Off Kona and Hilo	Biology	Honolulu	R. Young (UH)/ F. Tsuji	P. Munsch
08/19-08/28/87	Bempex III		Transit	San Diego		P. Munsch
09/04-09/19/87	CalCOFI 8709	Southern California Bight	Physical, chemical, and biological studies	San Diego	E. Venrick	P. Munsch
09/22-09/26/87		San Clemente Basin	Marine biology	San Diego	J. Childress (UCSB)	P. Munsch
09/30-10/05/87		Santa Catalina and Santa Monica Basin	Food chain biology	San Diego	A. Carlucci	P. Munsch
10/08-10/15/87	CaBS VII, I.I	Southern California Bight	Food chain biology	Los Angeles	E. Renger	P. Munsch
10/15-10/23/87	CaBS VII, I.II	Southern California Bight	Food chain biology	San Diego	N. Kachel (UW)	P. Munsch
10/26-11/10/87		Off Pt. Sur	Geochemistry	San Diego	C. Reimers	P. Munsch
11/13-11/28/87	CalCOFI 8711	Southern California Basin	Physical, chemical, and biological studies	San Diego	G. Hemingway	P. Munsch
02/01-02/12/88	CaBS VIII	Southern California Basin	Food chain biology	San Diego	F. Azam/ N. Kachel (UW)	P. Munsch
03/14-03/19/88		California borderlands	Food chain biology	San Diego	A. Carlucci	P. Munsch
04/05-04/08/88		Southern California Bight	Microbiology	San Diego	M. Ohman	P. Munsch
05/02-05/14/88		31°30'N, 121°30'W	Seismic and electric studies	San Diego	J. Orcutt/ C. Cox	P. Munsch
05/17-05/26/88		Santa Monica, San Pedro, Santa Cruz, Tanner basins and Patton Escarpment	Benthic flux studies	San Diego	D. Hammond (USC)	P. Munsch
06/01-06/05/88			Transit	Grays Harbor		P. Munsch
06/08-07/09/88		Washington continental shelf	Benthic flux studies	Grays Harbor	A. Devol (UW)	P. Munsch

TOTAL DISTANCE TRAVELED: 20,399.83 nautical miles OPERATING DAYS: 208

R/N Thomas Washington

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
06/29-08/04/87	Crossgrain VII	Equatorial Pacific	USC Lander; box cores	San Diego	D. Hammond/ W. Berelson (USC)	T. Desjardins
08/05-09/21/87			Overhaul			
10/08/87		Off San Diego coast	Sea trials	San Diego		T. Desjardins
10/16-11/06/87	Tortuga I	Galapagos Propagating Rift	OBS, Sea Beam, and explosives	Puerto Quetzal	J. Orcutt	T. Desjardins
11/09-12/01/87	Tortuga II	Galapagos Propagating Rift	Sea Beam and OBS deployment	Galapagos	J. Phipps-Morgan (MIT)	T. Desjardins
12/03-12/15/87	Tortuga III	Galapagos Propagating Rift	OBS instrument recovery	San Diego	M. Riedesel (UT)	T. Desjardins
01/08-02/07/88	RAITT I	East Pacific Rise	Geophysics	Acapulco	G. Purdy (WHOI)	T. Desjardins
02/11-02/13/88	RAITT II	East Pacific Rise	Sea Beam and dredging	Manzanillo	R. Batiza (NWU)	T. Desjardins
03/15-04/02/88	RAITT III	East Pacific Rise	Geophysics and Sea Beam	San Diego	P. Lonsdale	T. Desjardins
04/29-05/15/88	Roundabout I	35°N, 133°W	Sea Beam	Honolulu	J. Hildebrand	A. Arsenault
05/17-06/10/88	Roundabout II	23°N, 158°W	Seismic profiling/Sea Beam	Honolulu	R. Detrick (URI)	T. Desjardins
06/12-06/20/88	Roundabout III		Transit	San Francisco		T. Desjardins
06/24-07/23/88	Roundabout IV	Northeast Pacific	Physical, chemical, and biological studies	Newport	T. Cowles (OSU)	T. Desjardins

TOTAL DISTANCE TRAVELED: 33,315.5 nautical miles OPERATING DAYS: 240

R/P ORB

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	O-in-C *
08/02-08/27/87		33°-12°N, 118°-30°W	Multiple discipline seafloor experiments	San Diego	V. Anderson	T. Hoopes
06/28-07/07/88		San Diego Basin	Thruster tests	San Diego	V. Anderson	T. Hoopes
TOTAL DISTANCE TOWED: 334.6 nautical miles OPERATING DAYS: 32 *OFFICER-IN-CHARGE OF FLOATING PLATFORM						

R/P FLIP

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	O-in-C *
09/02-10/02/87	VLA I	35°N, 126°W	Array tests	San Diego	J. Hildebrand	D. Efird
11/09-11/20/87		San Diego Basin	Equipment test	San Diego	R. Pinkel	D. Efird
05/11-05/23/88		San Diego Basin		San Diego	R. Pinkel	D. Efird
TOTAL DISTANCE TOWED: 1,390 nautical miles OPERATING DAYS: 53 *OFFICER-IN-CHARGE OF FLOATING PLATFORM						

RESEARCH VESSELS OF SCRIPPS INSTITUTION OF OCEANOGRAPHY

	<i>MELVILLE</i>	<i>NEW HORIZON</i>	<i>ROBERT GORDON SPROUL</i>	<i>THOMAS WASHINGTON</i>	FLIP	ORB
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

1987-88 Total nautical miles traveled: 100,012.83 Total operating days: 925 *Depends on towing vessel

**With berthing vans



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.

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.

Dr. John A. Orcutt discusses plate tectonics with students in a geology seminar.



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, geochemistry, and cosmochemistry. 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

In the fall of 1987, 56 new students were admitted to graduate study. Of these, 16 were in marine biology, 8 in geological sciences, 8 in geochemistry and marine chemistry, 4 in geophysics, 9 in physical oceanography, 6 in applied ocean sciences, and 5 in biological oceanography. Enrollment at the beginning of the academic year was 197. UC San Diego awarded 22 Doctor of Philosophy degrees and 6 Master of Science degrees to the students listed below.

Doctor of Philosophy Degrees Awarded, with Titles of Dissertations

Earth Sciences

Susan E. Hough, "The Attenuation of High Frequency Seismic Waves."

Martin C. Kleinrock, "Detailed Structural Studies of the Propagator System Near 95.5°W on the Galapagos Spreading Axis."

Alan M. Volpe, "Petrogenesis and Sr-Nd Isotopic Geochemistry of Basalts from Western Pacific Backarc Basins and Precambrian Mafic Amphibolites and Diorites in the Delhi Supergroup, India."

Frank K. Wyatt, "Measurement of Continuous Strain: Pinon Flat Observatory."

Mary S. Lowery, "The Effects of Starvation on Protein Synthesis and Nucleic Acid Metabolism in the Muscle of the Barred Sand Bass *Paralabrax nebulifer*."

Linda H. Lutz, "DNA Repair in Deep-Sea Bacteria."

Joseph R. Pawlik, "Chemical Induction of the Larval Settlement of Honeycomb Worms (Polychaeta: Sabellariidae)."

Donald C. Porter, "Phosphorylation of Sperm Histone H1 During Sea Urchin Fertilization."

Carolyn A. Shumway, "Multiple Sensory Maps in Weakly Electric Gymnotiform Fish."

Annalisa C. Griffa, "Wind-Driven Circulation and Statistical Mechanics."

Katherine S. Hedstrom, "An Experimental Study of Homogeneous Lenses in a Stratified Rotating Fluid."

Scott J. Hills, "The Analysis of Microfossil Shape: Experiments Using Planktonic Foraminifera."

Homa J. Lee, "Geotechnical Properties of Northeast Pacific Ocean Sediment and Their Relation to Geologic Processes."

David J. Pierotti, "The Measurement of Trace Oxygenated Hydrocarbons in the Environment."

Barbara A. Price, "Equatorial Pacific Sediments: A Chemical Approach to Ocean History."

Daniel L. Rudnick, "Mass and Heat Balances in the Upper Ocean."

Timothy J. Shaw, "The Early Diagenesis of Transition Metals in Nearshore Sediments."

Thomas E. White, "Nearshore Sand Transport."

Marine Biology

Daniel L. Distel, "Characterization of the Symbiosis Between Chemolithoautotrophic Bacteria and the Bivalve *Lucinoma aequizonata*: Morphology, Biochemistry, and Phylogeny."

Kathryn A. Dickson, "Why Are Some Fishes Endothermic? Interspecific Comparisons of Aerobic and Anaerobic Metabolic Capacities in Endothermic and Ectothermic Scombrids."

Oceanography

James P. Barry, "Pattern and Process: Patch Dynamics in a Rocky Intertidal Community in Southern California."

Maria S. Gil-Turnes, "Antimicrobial Metabolites Produced by Epibiotic Bacteria: Their Role in Microbial Competition and Host Defense."

Master of Science Degrees

Marine Biology

Sandor E. Kaupp
Ngai C. Lai
Wendy L. Ryan

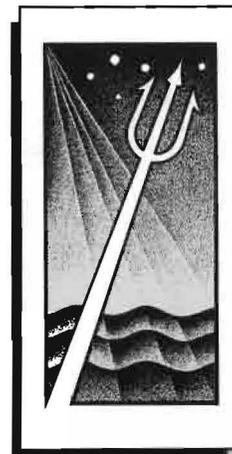
Oceanography

Bradley G. DeRoos
Thomas C. Fu
Jean-Marie Q. D. Tran

FACILITIES & 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 S60 scanning electron microscope with Ortec EDS II energy-dispersive X-ray spectrometer; 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.

Aquarium Facilities

There are two research aquarium facilities; each is provided with a dual-line system that delivers seawater at ambient temperatures, a single-line chilled seawater system, and compressed air. 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. 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.



Robert Snodgrass checks the maximum-minimum thermometer on the end of the pier. Below, seawater is pumped from the end of the pier into settling tanks.



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 nonrecreational 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 is 2 m wider and 15 m longer, is located immediately to the south of the former structure. It provides increased seawater flow for the support systems at Scripps and improved boat launching and sampling facilities.

Hydraulics Laboratory

This laboratory has a wind-wave channel $43 \times 2.4 \times 2.4$ m, with a tow cart for instruments and models; a two-layer flow chan-

nel, test section $1.1 \times 1.1 \times 16$ m; a 15×18 -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 $6 \times 12 \times 3$ -m concrete basin, a $10 \times 1 \times 1$ -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-m 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 processing 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.

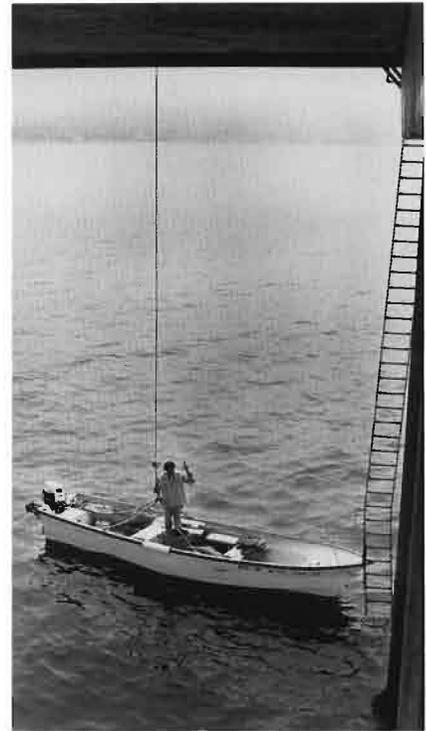
Mass Spectrographic Equipment

Nine 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; and a 3-cm mass spectrometer for stable isotope tracer measurements.

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.

B. Walton Waldorf maintains the tide gauge at the end of the pier for the National Oceanic and Atmospheric Administration. Below, Ronald R. McConnaughey prepares to remove a skiff from the water.



Physiological Research Laboratory Pool Facility

This facility includes a holding pool for large marine animals and fish, and a ring pool of 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. Weather advisories are

FACILITIES AND COLLECTIONS

routinely broadcast to the fishing fleet as well as to scientific vessels. 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 8×15-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 about 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 consists of intertidal rocky and beach environments; the underwater 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 3,800 serial titles and has more than 200,000 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 Digital Equipment Corporation Micro VAX II system that will handle data collection and archiving (using software developed at the University of Miami) and a Hewlett-Packard 9000 Series computer (using software developed by Global Imaging, Inc.) that will handle

data processing and analysis. Both systems will be significantly faster and have more storage capabilities than the present system. 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 SIO and the Southwest Fisheries Center. The raw seawater is filtered through three, 18-cm-diameter, high-speed sand filters and pumped 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 is pumped up to the National Marine Fisheries building. The system is capable of delivering a maximum of 6,500 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 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 programming, 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 (box corers, piston corers, dredges, etc.), operate net tows and trawls, and perform a wide variety of other tasks on Scripps research vessels. They also handle logistics for distant 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, available 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 Hewlett-Packard 1000 mini-computer as a shore-based processor, and seven Tektronix 4050 series micro-processors 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

SSURF provides remote access to the San Diego Supercomputer Center, which is situated on the UCSD campus. The Supercomputer Center provides scientists with some of the most powerful computers available for computationally intensive studies. The facility at Scripps furnishes a high-speed link to the center, enabling two-way transfer of data and interactive use. SSURF also offers electronic mail access to many of the major networks, including ARPAnet, OMNet, and BITnet.

In addition to accessing computers around the world, this facility provides

substantial computing capacity for local processing. The computer is a VAX 785 with the VMS operating system and a UNIX subsystem. Several plotters, printers, tape drives, and terminals are available around the clock.

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 46,000 students in educational groups participated in study trips to the aquarium-museum. The aquarium is open to the public daily; admission is free.

Aquarium-museum scientific 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, is currently being designed. The new building will be 2½ times larger than the present one and is expected to cost \$8.6 million.

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 29,000 lots of specimens sorted into major taxonomic groups such as Coelenterata, Echinodermata, 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 processing, 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 about 4,000 cataloged species, including 154 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 some 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.

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, James R. Hubbard, C-233, NOAA/NOS, 6011 Executive Blvd., Rockville, MD 20852. The Marine Life Research Group has kept a tide gage on Catalina Island from 1978 to 1988; daily records are available by writing Arnold W. Mantyla, A-030, Scripps Institution of Oceanography, La Jolla, California, 92093.

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.

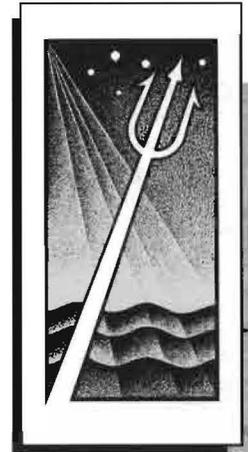
Scripps Core Repository of the Ocean Drilling Program

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.

APPENDIXES

APPENDIX A

PUBLICATIONS



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 1988. Detailed information on the availability of each series is included.

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 Platytroctidae (Pisces: Salmoniformes). 1987. 159p.
- v.27 **Wilson**, George D. F. Systematic Revision of the Deep-Sea Lipomerinae in the Isopod Crustacean Family Munropsidae. In press.

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-075C, La Jolla, California 92093.

The articles listed below were published in the 1987 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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B. Call

APPENDIX B

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

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CS—California Space Institute
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DSDP—Deep Sea Drilling Project
D-SIO—Department of the Scripps Institution of Oceanography
ECS—Department of Electrical and Computer Science Engineering
GRD—Geological Research Division
IGPP—Institute of Geophysics and Planetary Physics
IMR—Institute of Marine Resources
IPAPS—Institute for Pure and Applied Physical Sciences
MBRD—Marine Biology Research Division
MLRG—Marine Life Research Group
MPL—Marine Physical Laboratory
NR—Natural Resources
NU—Neurobiology Unit
ORD—Ocean Research Division
PRL—Physiological Research Laboratory
SC—Scientific Collections
SGP—Sea Grant Program
SOMTS—Ship Operations and Marine Technical Support
SPP—Science and Public Policy
VL—Visibility Laboratory

APPENDIX C

AWARDS AND HONORS

Dr. Andrew A. Benson Received the Sigma Xi Award of Special Merit from the Sigma Xi chapter of San Diego State University.

Dr. Wolfgang H. Berger Elected a Fellow of the American Association for the Advancement of Science.

Dr. Theodore H. Bullock Received UC Berkeley's Berkeley Citation award.

Dr. Harmon Craig Corecipient of the 1987 Vetlesen Prize from Columbia University.

Dr. Russ E. Davis Elected to the National Academy of Sciences.

Dr. Jeffrey H. Graham Received a J. S. Guggenheim Fellowship.

Dr. Douglas L. Inman Received the International Coastal Engineering Award from the American Society of Civil Engineers.

Dr. Marvin K. Moss Received the Distinguished Civilian Service Award from the United States Navy.

Dr. William A. Newman Elected a Fellow of the American Association for the Advancement of Science.

Dr. Melvin N. A. Peterson Appointed chief scientist of the National Oceanic and Atmospheric Administration by President Ronald Reagan.

Dr. Robert Pinkel Elected a Fellow of the Acoustical Society of America.

Joseph L. Reid Received a Special Creativity Award from the National Science Foundation.

Dr. Kenneth L. Smith Received a Special Creativity Award from the National Science Foundation.

Dr. George N. Somero Elected to the National Academy of Sciences.

James R. Stewart Received the Golden Trident Award from the International Academy of Science and Submarine Technology.

Dr. James J. Sullivan Received a Visiting Fulbright Research Scholarship to Japan.

Dr. Peter F. Worcester Elected a Fellow of the Acoustical Society of America.

APPENDIX D

CURRENT FUNDS

Agency	Expenditures*	Percentage of Total
Federal Government		
National Science Foundation	19,766,170	30.10
Navy, Department of the	16,734,442	25.48
Commerce, Department of	2,083,558	3.17
National Aeronautics and Space Administration	2,027,486	3.09
Health and Human Services, Department of	1,370,108	2.09
Energy, Department of	613,346	0.93
Army, Department of the	1,149,914	1.75
Interior, Department of the	566,829	0.86
Air Force, Department of the	548,066	0.83
Defense, Department of	29,136	0.04
Other	52,442	0.08
Total Federal Government	\$44,941,498	68.42
State General Funds	15,080,338	22.96
Private Gifts and Grants	5,971,519	9.09
Overhead Funds	1,069,538	1.63
State of California	549,386	0.84
Endowment Funds	-368,479	-0.56
Local Government	35,285	0.05
Sales and Services	-1,598,780	-2.43
Total Current Funds Expenditures	\$65,680,305	100.00

*Includes overhead

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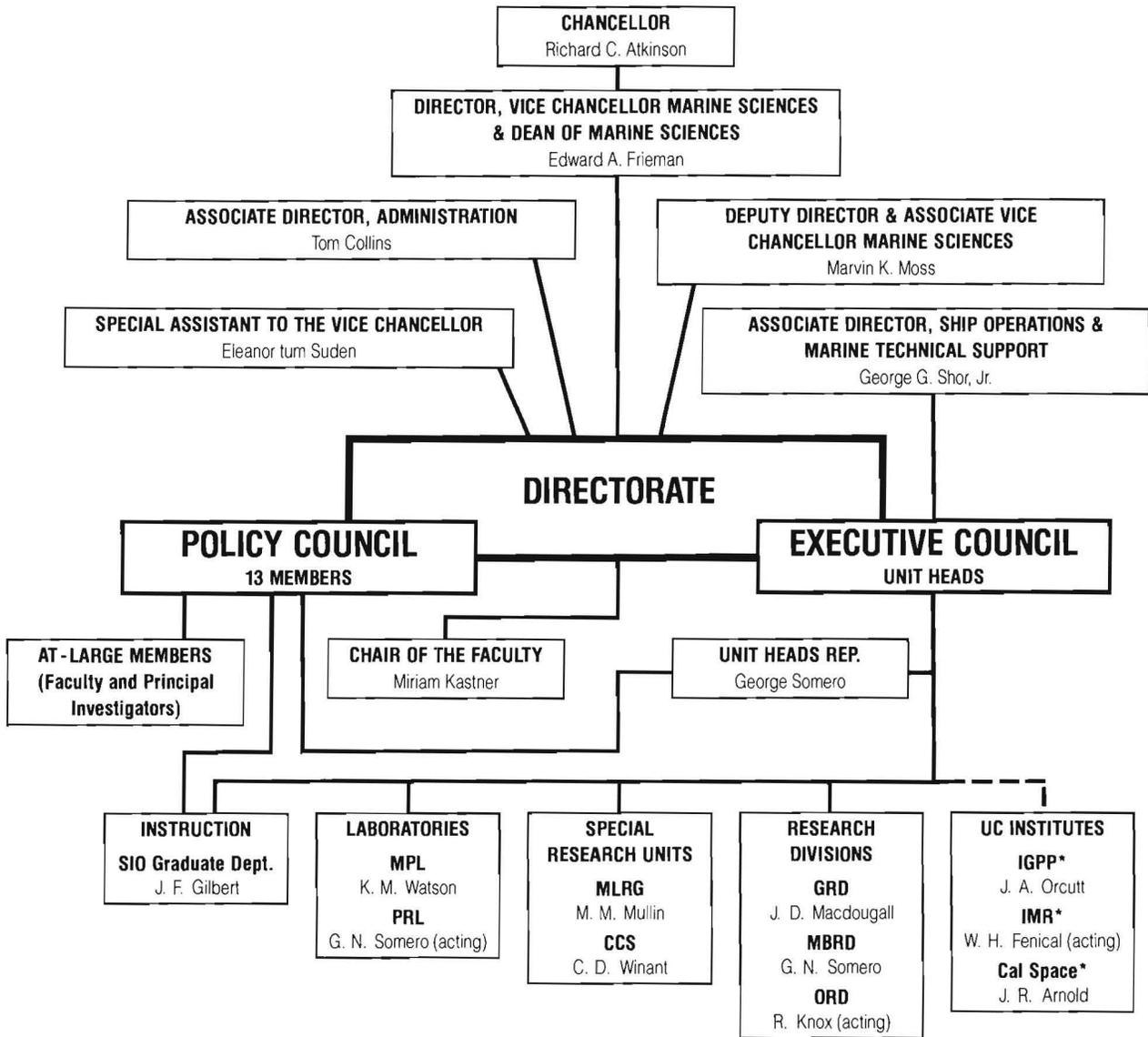
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 GRD Geological Research Division
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 IMR Institute of Marine Resources

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

*Reports to the Vice Chancellor—Marine Sciences

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IN MEMORIAM



Abraham Fleminger. January 13, 1988. Dr. Fleminger was a research biologist/curator in the Marine Life Research Group from 1960 through 1988 and was a senior lecturer in the Scripps Graduate Department since 1967. He was one of the world's most highly regarded authorities on copepods, commonly known as "insects of the sea."

Robert M. Garrels. March 8, 1988. Dr. Garrels was one of the leading scientists in the field of geochemical modeling, and spent 1969 through 1971 as professor of geology in both the Geological Research Division and the Scripps Department.

A. Baird Hastings. September 24, 1987. A renowned biochemist, Dr. A. Baird Hastings maintained an office in the Physiological Research Laboratory from 1977 through 1987. He was a member of the National Academy of Sciences.

Lemar P. Hayes. March 27, 1988. Lemar Hayes was cruise operations manager in the Deep Sea Drilling Project from 1970 to 1974.



Laura Clark Hubbs. June 24, 1988. For 40 years, Laura Hubbs was an unpaid, full-time assistant and keeper of the records for her husband, the late Professor Carl L. Hubbs.

Francis (Frank) L. LaQue. January 1988. Frank LaQue worked at Scripps as a research associate in the Marine Physical Laboratory from 1976 through 1977 and also served several times as a senior lecturer in the Scripps Department.



Reuben Lasker. March 12, 1988. Dr. Lasker was a Rockefeller Postdoctoral Research Fellow at Scripps in 1956 and served as an adjunct professor of marine biology at Scripps since 1966. He was also chief of the Coastal Fisheries Division at the Southwest Fisheries Center of the National Marine Fisheries Service.

Mark T. McMillan. November 14, 1987. Mark McMillan was a diving volunteer in Antarctica from September through November of 1987.

Lillian F. Musich. July 12, 1987. Lillian Musich joined Scripps's Deep Sea Drilling Project in 1969, and remained until its closing in 1987. She was manager of the East Coast Core Repository.



Hans A. Panofsky. February 28, 1988. Dr. Panofsky was a research associate in the Ocean Research Division from 1984 until his death. He came to Scripps after completing 40 years as a professor at Pennsylvania State University.

William B. W. Rand. March 9, 1988. Dr. Rand was the first project manager of the Deep Sea Drilling Project, from 1966 to 1967.

C. Earl Short. January 31, 1988. C. Earl Short served as assistant director of Scripps from 1954 through 1958.

All correspondence pertaining to this specific report should be directed to: **Technical Publications, A-033B, Scripps Institution of Oceanography, La Jolla, California 92093-0233.**

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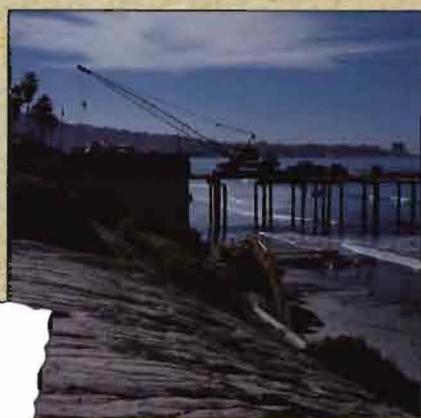
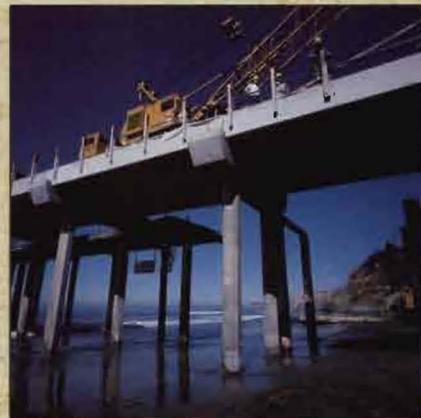
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Front and back covers show the **Ellen Browning Scripps Memorial Pier** near completion as the old pier is being torn down. B. Call

Title page: **Scientist at work during a cruise.**

M. Clark

Pictures at right were taken during construction of the new pier. Below are archive pictures of the first Scripps Pier under construction in 1915.



B. Call



SIO Archives. Hand colored by J. Swanson

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