

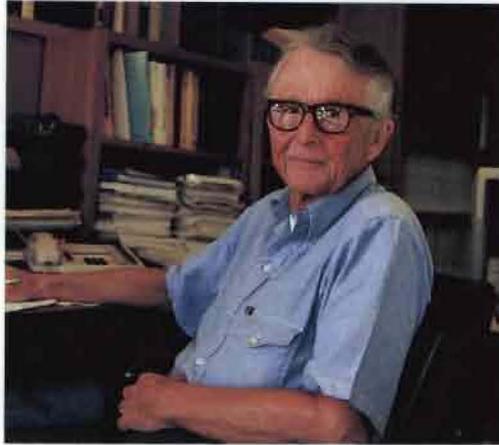
UCSD

SCRIPPS INSTITUTION OF OCEANOGRAPHY

ANNUAL REPORT 1987



UNIVERSITY OF CALIFORNIA, SAN DIEGO

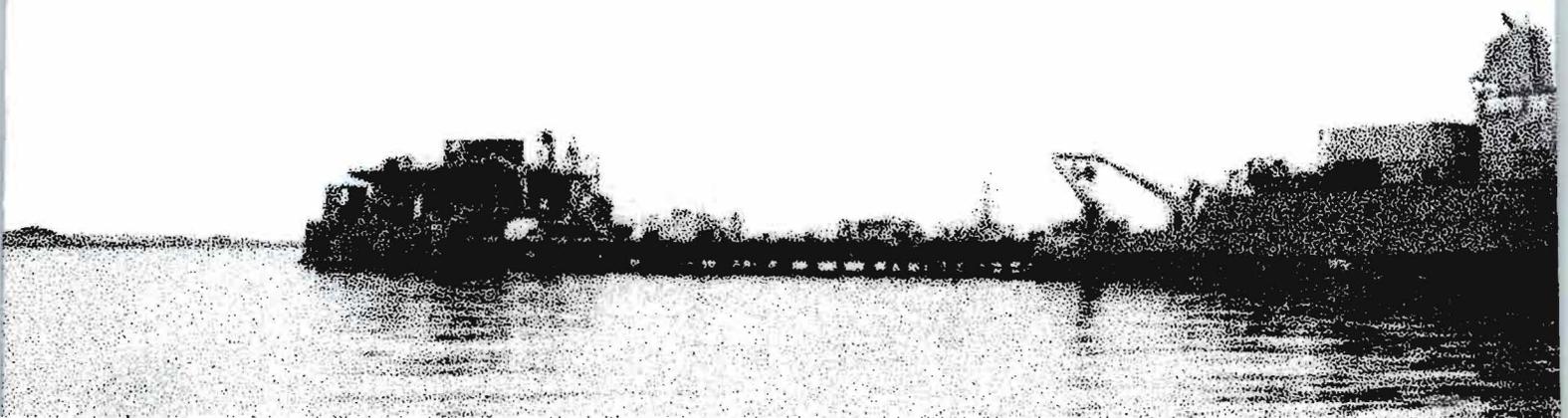


After more than twenty years in aeronautical and electrical engineering, John Miles turned his mathematical abilities to a wide range of problems in fluid dynamics when he came to Scripps Institution of Oceanography in 1964. An avid ocean swimmer and surfer, he was drawn to the institution by a desire to work with Walter Munk and others investigating wave motion at the Institute of Geophysics and Planetary Physics.

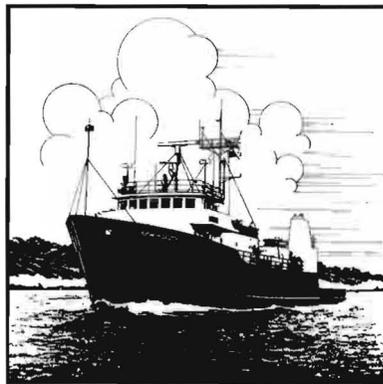
Miles conducted his undergraduate and graduate studies at Caltech, receiving a doctoral degree in 1944. During World War II he worked at the MIT Radiation Laboratory and Lockheed Aircraft Corporation, and in 1945 he joined the (then) new Engineering Department at UCLA. In 1962 he moved to Australia for three years before coming to UCSD as a professor with a joint appointment in the Department of Applied Mechanics and Engineering Sciences and IGPP.

In addition to teaching and research, Miles has served in important administrative positions at UCSD, including chairman of the AMES department, chairman of the Academic Senate, and vice chancellor for academic affairs. He has received Fulbright and Guggenheim fellowships, and he is a member of the National Academy of Sciences and a fellow of the American Academy of Arts and Sciences, the American Academy of Mechanics, and the American Institute of Aeronautics and Astronautics. He is a prolific writer, and his more than 300 papers are widely cited in several scientific fields. His work in the stability of stratified shear flows resulted in the Miles-Howard Theorem.

Although he explores a world of theoretical chaos, Miles's life is the essence of order. He works in his office six days a week, nearly twelve hours a day, on a strict schedule for every activity from student conferences to daily bicycle rides to the UCSD swimming pool. Colleagues describe him as one of the most efficient and scholarly scientists who has ever lived—in large part because of his insatiable curiosity and his love for the pursuit of knowledge.

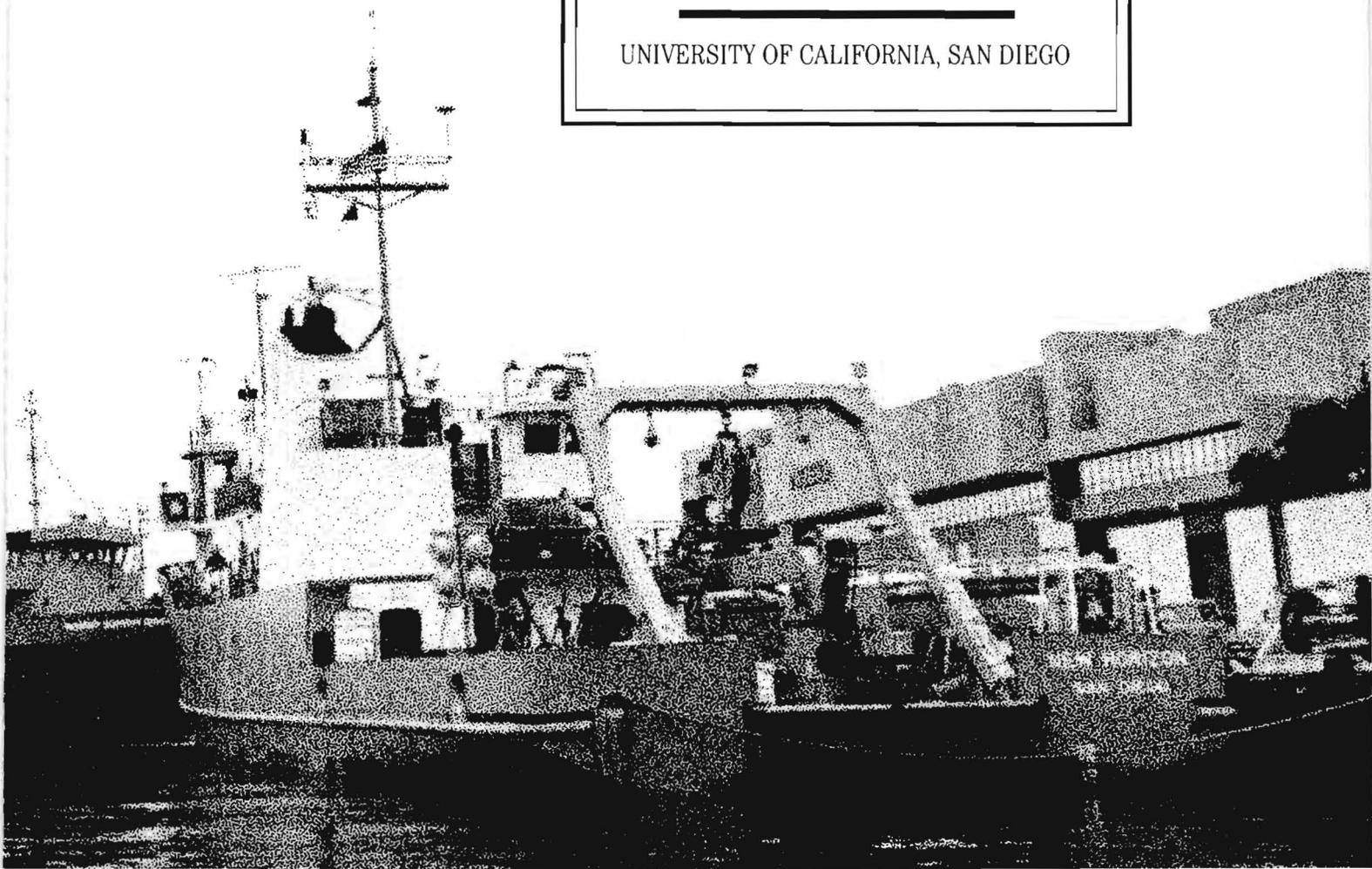


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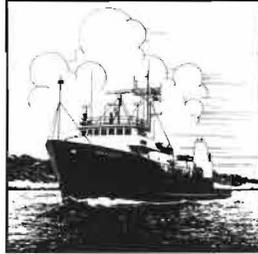


ANNUAL REPORT 1987

UNIVERSITY OF CALIFORNIA, SAN DIEGO



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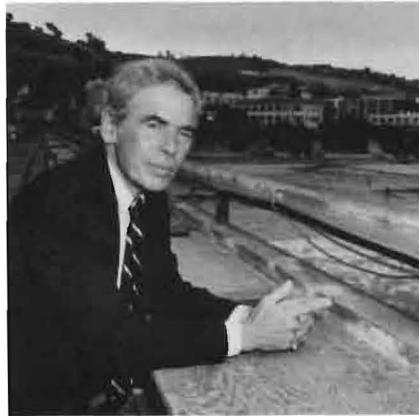


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Introduction

This report covers my first full year as director of Scripps. It was a year of introspection and institutional self-analysis. The two planning committees I established spent many hours diligently considering Scripps's future. We are now acting on many of their recommendations. To help Scripps respond to emerging trends in science, the committees thought we needed more flexibility in using state-funded research and faculty positions. Therefore we will pool these resources beginning with the new fiscal year. The committees' proposal that Scripps create an undergraduate training program is possibly the most far-reaching. Although UCSD is a broad-based and diverse undergraduate institution, the earth sciences are only marginally recognized in its curriculum. The Scripps faculty is the most qualified to set up and operate such a department at UCSD. Accordingly, we have formed a committee to explore how we might contribute in this important area.

A new direction in science, both nationally and internationally, is the "Global Change" or "Global Geosciences" initiative. In the United States, numerous government agencies are involved in efforts to understand our planet as a total system. I believe Scripps is in an excellent position to assume a leadership role in this arena. I have therefore requested funding from the University of California for a major organized research program in global change processes. This idea has been well received, and I trust that next year we will be able to move forward aggressively.



B. Call

I have approved and implemented a new organizational structure for the central management of Scripps that consists of two committees: the Policy Council, which will consider major policy matters, long-range planning, and will advise me on major resource allocations, including academic positions; and the Executive Council, which will handle the day-to-day operation of the institution and implement the Policy Council's recommendations. This structure broadens the base for input to the decision-making process and will provide diverse sources of advice for me.

Several other organizational changes are also in process or anticipated. As of July 31, 1987, the Visibility Laboratory will close and its staff will be absorbed into other campus units. Marvin Moss will join us as Associate Vice Chancellor, Marine Sciences and Deputy Director of Scripps. Michael Mullin will direct the Marine Life Research Group after Joe Reid's retirement. Freeman Gilbert will chair the SIO Department, leaving John Orcutt as the sole associate director of IGPP. Fred Spiess will retire as director of IMR to pursue full-time research, and Fred White, director of PRL, will retire from the university.

Several present and former staff members died this past year, and I particularly want to note the passing of Gifford Ewing, Alfred B. Focke, Rudolph W. Preisendorfer, and Marston C. Sargent.

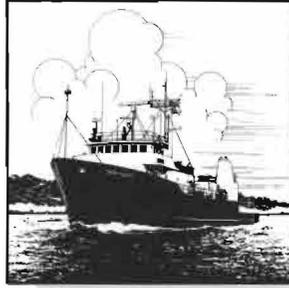
Individual honors are listed elsewhere in this annual report, but I want to mention some institutional recognition that we received. The 1987 Offshore Technology Conference gave Scripps its Distinguished Achievement Award for more than eight decades of pioneering work in ocean and marine technology. In addition, the staff of the Deep Sea Drilling Project received the Meritorious Public Service Award from the National Science Foundation.

I am most enthusiastic about the future for Scripps. We have one of the finest groups of scientists and staff that I have seen assembled in one organization. Our institution is strong and vigorous, and despite the uncertain and transitory federal budget picture, I am sure that we will continue to grow and prosper long into the future.

A handwritten signature in dark ink, reading "Edward A. Frieman". The signature is written in a cursive, flowing style.

Edward A. Frieman, Director
Scripps Institution of Oceanography

Highlights



SEAMOUNTS YIELD SECRETS

From the observation port of the submersible, the wall of the crater looms as a sheer, bleak scarp—an exposure of lava in the center of a long-dead submarine volcano blackened with manganese oxides accumulated over millions of years. The wall disappears above and below into darkness beyond *Alvin*. The charts of this volcano, obtained from high-resolution narrow-beam sonograms, show the cliff to be about 250 m high, and nearly vertical. Two observers and a pilot are inside the submersible, an air bubble in a pressure sphere held down by weights in more than 3,000 m of water.

The pilot maneuvers the bubble up the face of the cliff, occasionally stopping to extend one of the submersible's mechanical arms to nibble off a rock sample and drop it into a compartmentalized basket. The submersible, neutrally buoyant in the deep water, remains suspended against the cliff, occasionally jostling as the arm grips its quarry.

The observers note each sample's location, size, shape, and color in the unbalanced lighting provided by *Alvin*. They photograph and describe the surroundings, writing notes and talking into tape recorders. If the sample is not washed out of the basket by waves when *Alvin* returns to the surface, the rock and its companions will be tagged or labeled, bagged or boxed, and carted off to a shipboard laboratory for the first stages of what will eventually

Dr. James Natland analyzes minerals in thin sections from a submarine volcano, using the electron microprobe at Scripps.





Arm of Alvin retrieves a rock sample from a submarine volcano.

P. Lonsdale

result in a column of numbers disclosing its composition. From these numbers and descriptive information, the rock will become known to a wide community of scientists, who will ponder the life history of the volcano from which the rock came. The rock itself will return to darkness, filed in the recesses of a cabinet drawer in one of the laboratories at Scripps Institution of Oceanography.

During the two-week cruise, ten dives are made, and more than a hundred rock samples are obtained. These, and samples acquired by conventional dredging operations, are used to characterize a small part of a vast province of submarine volcanoes—or seamounts, as they are more usually called—lying off southern California and northern Mexico. The nearest volcanoes are less than a day's steam from San Diego.

The research is only part of a diverse effort by individuals and groups of investigators at Scripps to understand some of the many thousands of Pacific Basin seamounts, both known and undiscovered. Although seamounts exist in all ocean basins, the gentler slope of most of

the Pacific seafloor makes seamounts here particularly easy to identify with the conventional, wide-beam, echo-sounding equipment installed on most Scripps vessels. Unfortunately, such equipment can do little more than indicate the locations, general shapes, and elevations of the steeply sloped volcanoes.

In the last few years there has been a flurry of activity resulting from the advent of multiple narrow-beam echo sounding. Sea Beam instrumentation, installed on board Scripps's R/V *Thomas Washington*, simultaneously produces sixteen separate, narrow pulses of sound, which echo from the seafloor. These pulses are resolved by computer into detailed bathymetric charts having much greater resolution than charts drafted by hand from older, wide-beam techniques. Where small bodies of rock on the seafloor produced only diffuse or rounded shapes on echograms, the same features are now resolved into pinnacles or small volcanic cones. The slopes of steeply faulted, cratered walls can for the first time be seen and precisely determined. The highly accurate charts

allow careful sampling, and reveal specific targets for near-bottom surveys with towed equipment and dive programs. The charts support geophysical studies that plumb the interior structure and magnetic fields of the volcanoes. Not surprisingly, the seamounts near San Diego were among the first to be charted using Sea Beam, and have been the subject of several follow-up studies that have widened our knowledge of submarine volcanoes.

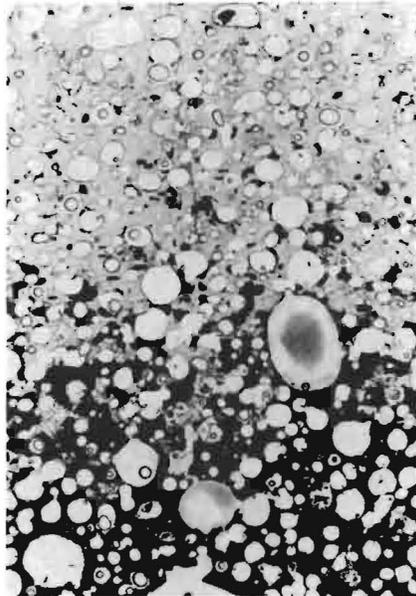
An important aspect of the work is the determination of when and where the seamounts formed. We now think that there are two general seamount types in the region west of southern California. One group formed about 20 to 30 million years ago as isolated features or short strings of cratered mountains on very young crust near ancestral spreading ridges. The second type is a linear chain (much like that of the Hawaiian Islands), which is about 12 million years old at Jasper Seamount near its center, and has a young island—Guadalupe, a part of Mexico—near its eastern end.

A comparison of thin sections showing quenched glassy margins of pillow lavas from underwater seamounts off California. The sample on the bottom has no vesicles (gas bubbles) and only a single composite mineral aggregate of plagioclase. The sample on top has many vesicles and crystals of olivine. Both samples show clear, glassy margins at the top; these margins develop when the lava is quenched in cold seawater. The dark spots represent attempts of the lava to form crystals during quenching. These increase away from the glassy edge, and coalesce about 1 cm into the lava, where cooling rates were lower.

The two types of seamounts differ greatly in their lava composition. For example, the linear-chain lavas have higher Na_2O and lower MgO contents than most lavas from the older seamounts, and have as much as 400 times more K_2O . This is only one indication of fundamentally different compositions in rocks from lava source regions, where melting occurs in the mantle. Geochemists use other indicators—trace elements and radiogenic isotopes—to decipher convective patterns in the mantle, and to specify how the different sources originated early in the earth's history.

The volcanoes of the younger linear chain are larger than the older volcanoes, and most of the lavas erupted in shallow water. The westernmost volcano of this chain off California, named Fieberling, is, in fact, a flat-topped seamount, or guyot, that was once an island that experienced erosion, and is now submerged. Different lava types erupted in deep water, in shallow water, and on the island. In deep water, on the older volcanoes, lavas are mainly the glass-rimmed tubular flows called pillows, which erupted fairly passively. In shallow water, on most of the younger chain's surface exposures, gases expanded in the molten material, and seawater meeting the lava turned to steam, shattering the erupting material to breccias. These breccias cascaded down submarine slopes to form smooth, bedded carapaces of fragmental volcanic glass. On the island, with no seawater to convert to steam or water pressure to act on the erupting material, lava flows lost their gases to the air and formed massive flows with few interior vesicles (gas bubbles).

The submarine volcanic breccias appear to be especially conducive to the formation of thick encrustations of manganese and iron oxyhydroxides. The breccias and most of the pillow lavas are quite altered, probably because of extensive seawater flux through the porous rocks, promoted by the presence of molten ma-



J. Natland

terial deep within the volcanoes. The encrustations precipitated from the seawater that circulated in the volcano, and from bottom waters over the millions of years that followed the volcanic activity. The latter encrustations may contain substantial quantities of nickel and cobalt, and thus may be a resource for mining within the exclusive economic zone of the United States.

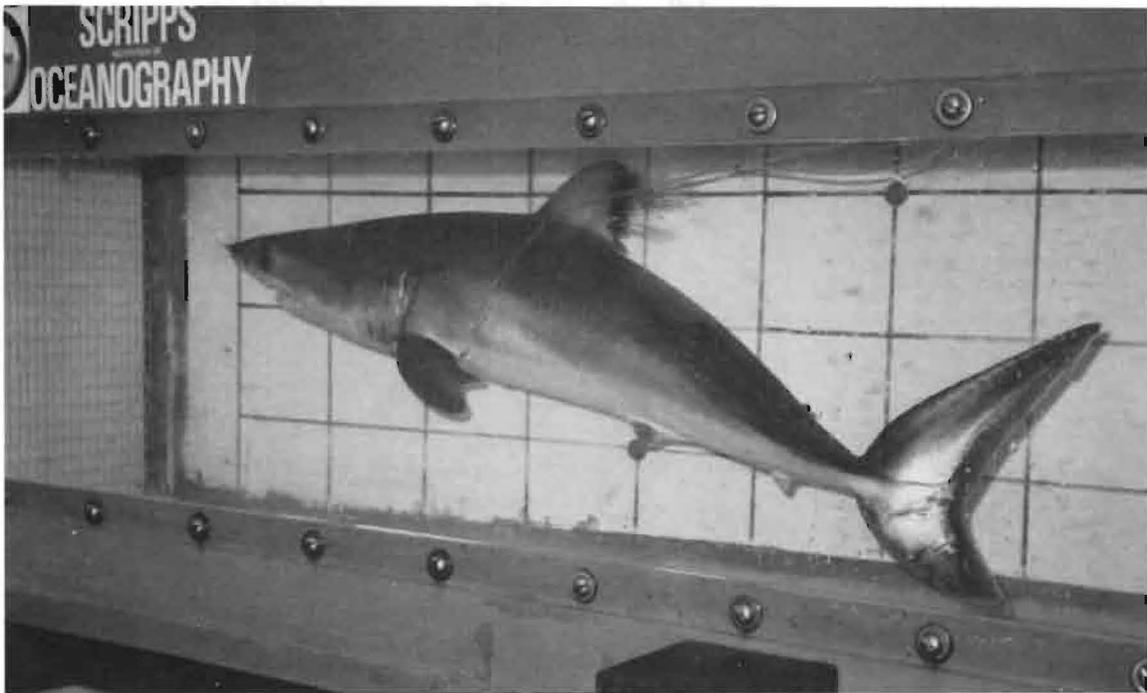
The distribution of volcanic breccias and their high porosity accord with the results of geophysical studies at Jasper Seamount. There an array of ocean-bottom seismographs was deployed around the seamount's flank to detect arrivals of sound from a series of explosions set off on the seafloor. A technique called tomography, together with the high-resolution Sea Beam bathymetry, was used to map the interior seismic velocity of the seamount. The procedure reveals slow average compressional-wave velocities within the body of the seamount. The velocities indicate that Jasper is composed mostly of explosively erupted rock rather than dense lava flows or intrusive rocks, and suggests that it formed primarily from shallow-water summit eruptions.

Knowledge of the detailed shape of the volcano also makes it possible to determine its interior magnetic structure. The magnetic field of Jasper Seamount has been measured from surface ships and with deep-towed magnetometers. A procedure called inverse theory allows the internal magnetization to be estimated. Because magnetic minerals that form in quenching lavas assume the direction of the earth's magnetic field at the time they erupt, lava flows erupted at different times are magnetized in different directions. The composite magnetization of the seamount can be modeled using the computer technique. A complex pattern of magnetization near the summit indicates that late eruptions overlapped a reversal of the earth's magnetic field. The overall magnetic field also is evidently modified by intrusive rocks such as dikes in the seamount interior.

These are innovative procedures, and the results are first glimpses of the internal structure of seamounts. Careful interdisciplinary study of different classes of seamounts, and perhaps ocean drilling may reveal contrasts in how seamounts form, and their full economic potential.

James H. Natland and
John A. Hildebrand

WATER TUNNEL RESPIROMETER



Mako shark (Isurus oxyrinchus) equipped with electrocardiogram wires swims in the water treadmill during experiments at sea.

N. Lai

A marine biologist's dream has become a reality at Scripps with the completion of a portable water tunnel. Now, with this device, scientists can study the behavior, locomotion, and physiology of large pelagic fishes—tunas, mackerels, jacks, and sharks. Most of these fishes must swim steadily in order to breathe, and they are too big for most research devices or to keep in holding tanks aboard ships.

Dr. Jeffrey B. Graham designed this water tunnel to make possible the study of swimming tuna. This water tunnel with windows accommodates fish just over 1 m long; the

water recirculates at the speed required to maintain a continuously swimming fish in the least amount of space. The system operates like a treadmill, and allows monitoring of large, swimming fishes for the first time.

Developed at the Physiological Research Laboratory, the water tunnel is a closed system with plastic pipes and other components that form an oval structure mounted on a 5.5 × 6.1-m wooden pallet. This device can be placed on research ships and taken to sea for work with species that could not otherwise be studied. When the system is filled with water, it weighs nearly six tons.

The working tunnel section has lucite windows on one side and on the top so that animals can be viewed and photographed while they swim against the flow. Water flow through the instrument—regulated by a variable-speed, 40-hp, 460-V motor—is driven by two 30-cm boat propellers mounted in tandem on a stainless steel shaft. Speeds of 2.5 m per second can be attained in the working section. Two unique features of the water tunnel are its custom-made fiberglass diffuser and contractor sections placed on the inflow side of the working section to smooth water flow.

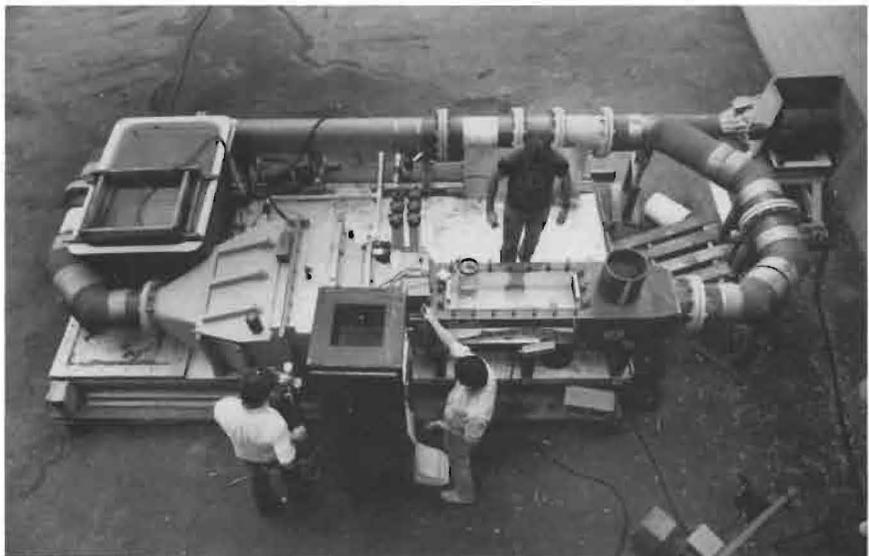
Dr. Graham inspects the inner surface of the water tunnel's working section. Below, aerial view of the water treadmill, note leopard shark resting in the working section at center.

To achieve desired experimental conditions the system has a reservoir where seawater can be mixed with varying levels of oxygen, a filter to maintain water quality, and chillers for temperature control. Computers control the operations and log physiological data about the test specimen, including oxygen consumption, body temperature, muscle activity, and heartbeat.

Dr. Graham studies the swimming energetics and physiology of sharks and tunas. He will use the apparatus as a large-scale respirometer to measure the rate of oxygen consumption of swimming fish. Unlike most fishes, which are cold-blooded, tunas and certain sharks have the unusual distinction of being warm-blooded and can maintain a body core temperature that is 5°-14°C warmer than the surrounding seawater. Because muscle tissue is more efficient when heated, warm-bloodedness makes the tuna one of the most enduring swimmers in the ocean. Through the water tunnel experiments, Dr. Graham and his colleagues will be able to determine a tuna's preferences for water temperature and oxygen content. Such data could reveal information about tunas' range of natural habitats and their responses to small-scale environmental changes that may affect their distribution, productivity, and survival.

So far, the group has tested several sharks in the treadmill. In the leopard shark (*Triakis*) they documented ram-gill ventilation, which occurs when the swimming fish stops actively ventilating its gills and depends instead on its forward momentum for ventilation. Aquatic birds and an alligator are among the other animals that have been tested in the tunnel.

Dr. Graham just completed sea tests with the tunnel aboard R/V *Robert Gordon Sproul*, where the instrument ran with near perfection for eight full days. The researchers measured the swimming metabolism and heart rate of mako sharks (*Isurus oxyrinchus*) and calibrated telemetered heart-rate data from a colleague's transmitters with data obtained by "hard wiring." They also successfully



J. Chow

tested swimming sharks and yellow-tail in the tunnel in Dr. Graham's laboratory. The shipboard success demonstrates the feasibility of using the tunnel at sea for albacore studies.

The water tunnel, designed and constructed with National Science Foundation funds, is also available to marine researchers from other uni-

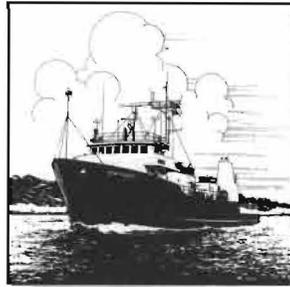
versities and institutions. The water tunnel should yield valuable basic data about fish and other aquatic animals, as well as information beneficial to the commercial and sport-fishing industries, and fisheries management.

Jeffrey B. Graham

Research Activities

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 the 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.



GEOLOGICAL RESEARCH DIVISION

Studies in the Geological Research Division (GRD) range from the earth's interior regions to the seafloor, and from the atmosphere to the outer reaches of the solar system. In this publication, there is space to summarize only a few of these studies. GRD research encompasses laboratory work and a strong field component. This year's highlights include studies at sea in the Central Pacific and in the Mariana Basin, as well as on land in the Himalayas, western China, and western India.

Researchers in Dr. Gustaf O. S. Arrhenius's group are studying problems related to the earliest stages of the ocean. Relics from this time are the most ancient preserved sedimentary rocks and the oldest life forms. To clarify the origin of carbon-based life from simple organic and inorganic structures, the researchers must investigate how organic compounds could be generated, selectively concentrated, and then reacted to form the ordered, functional polymers characteristic of evolved life. In the case of primordial RNA or RNA-like structures, the question concerns sugars or sugar-related compounds, phosphate, and cyanide-derived bases.

Dr. LeRoy M. Dorman checks the analog system of an ocean-bottom seismograph in preparation for a cruise. These instruments, developed at Scripps, have been in use for nearly a decade and make it possible to replicate a modern, above-ground seismic observatory on the seafloor. They have been used for studying seafloor structure and noise, and for mapping earthquake locations.



The workers have identified a group of minerals that may have played an important role in concentrating these compounds from dilute solution. The group comprises divalent-trivalent metal hydroxide sheet structures with anion exchange properties, and includes green rust. Judging from the remains in preserved sediments, green rust must have been abundant in the Archaean ocean: most of the world's currently exploited iron ores appear to be derived from this type of mineral.

Among the notable properties found for green rust is its ability to concentrate cyanide ion from dilute solution ($\leq 10^{-6}$ M) while being catalytically converted to minute particles of magnetite $[\text{Fe(II)}_0.\text{Fe(III)}_2\text{O}_3]$, with crystallite size of about 30 nanometers. Cyanide, sorbed on the large surface area of the magnetite, reaches mass concentrations of several percent and thus forms a dense reservoir of the material from which the genetic coding structure may be built; the pyrimidine base adenine, for example, consists of five molecular units of hydrogen cyanide. An important question arises: How easily can the sorbed, concentrated cyanide be protonated and brought into chemical reaction? In other words, is the concentration process a dead end, or a part of the evolution of life?

Another question is being addressed by Dr. Wolfgang H. Berger's paleoclimate group: Is climate changing now, as a result of the anthropogenic greenhouse effect? The recent El Niño event is a case in point: Did this event occur because of increased carbon dioxide in the atmosphere? To gain perspective on this question, Drs. Berger, Arndt Schimmelmann, and others are reconstructing the climate of the California Current, based on cores from offshore basins, especially the Santa Barbara Channel. There, sediments are varved, and preserve year-to-year information on temperature and biological productivity. The last 50 years are being investigated in great detail to obtain a calibration of the record

against conditions actually observed. As these studies proceed, ever older sediment layers, reaching back to centuries without written record, will be investigated. The researchers hope to accumulate a complete El Niño stratigraphy for the last 1,000 years, as well as data on general climate variability. Against this background, the question of whether the present climate trends are out of the ordinary can be answered.

Dr. Harmon Craig and colleagues in the Isotope Laboratory discovered new areas of hydrothermal vents located in non-Midocean Ridge sites, and sampled them with the Woods Hole Oceanographic Institution's deep submersible R/V *Alvin*. Drs. Craig, Yoshio Horibe, and David R. Hilton, and a colleague made a series of dives into the caldera of Loihi Seamount, the current site of the Hawaiian hotspot. Low-temperature vents (about 30°C) were found on the southern rim of the caldera, with shimmering warm water flowing down over red terraces with white orifices lined with bacterial deposits. The waters were found to contain 7,000 cc(STP) of CO₂ per liter, more than 140 times the total CO₂ content of normal seawater, and fully 4,000 times the concentration of "free CO₂" in seawater. This high CO₂ content makes the density of the vent water greater than ambient seawater, explaining the downward flow.

In April, Drs. Craig and Horibe, with graduate student Kenneth A. Farley and other colleagues employed *Alvin* on a back-arc basin spreading axis, making 10 dives to 3,600 m in the Mariana Trough. The area was surveyed using a Sea Beam map made last year on Papa-Tua Expedition by Dr. Craig and a colleague. Two main hydrothermal vent areas were found: a low-temperature area (30°C) with high concentrations of anemones, and a high-temperature (285°C) area of large chimneys and profuse sulfide mounds. A low-temperature area within this region was populated almost entirely by whelks and barnacles, mussels, and both types of hydrothermal area crabs;

gastropods (hairy types) were observed in the vent areas. The chimneys emit clear fluid devoid of sulfides at high temperatures. The chimneys contain sulfides (sphalerite and chalcopyrite) as initial deposits, but studies by Dr. Miriam Kastner show that the most recent parts comprise silica and barite, an unusual composition.

Dr. Craig and Valerie K. Craig worked in the Tengchong area of western Yunnan in southwest China near the Burmese border collecting hot-spring and volcanic gases and rocks. This area is one of the few recently active volcanic areas in China. The Craigs' work is part of a general study of the belt from the Indonesian arc through the Tengchong volcanics, north and west into Tibet.

Dr. Robert J. Poreda studied the helium isotopic composition of arcs throughout the Pacific and Indonesian regions, and found that about halfway along the Indonesian arc there is a remarkable transition from mantle to crustal helium composition, corresponding to the transition from oceanic to continental plate subduction. Scientists in the isotope laboratory completed the first isotopic study of methane in polar ice cores (complementing the previous work, which showed that the CH₄ content of the atmosphere has doubled in the past few hundred years).

Drs. LeRoy M. Dorman, John A. Hildebrand, and Allan W. Sauter, and graduate students conducted an experiment to map the internal structure of Jasper Seamount, located about 480 km west-southwest of San Diego. This seamount, in water 4 km deep, rises to within 600 m of the surface. An array of ocean-bottom seismographs was placed on the seamount flank at 3,000 m, and was precisely located with a transponder network. Twenty-six explosions were fired on the seamount in a circular pattern. The shots were fired on the bottom, rather than in the water, so that shear waves as well as compressional waves would be generated. Low compressional and shear velocities indicate that clastic rocks

predominate in the seamount. Dr. Hubert H. Staudigel and two graduate students dredged numerous rock samples during the experiment, using the precision navigation afforded by the transponder network.

Dr. James W. Hawkins crossed from Lhasa, Tibet, to Kathmandu, Nepal, to study the collision belt between Asia and India. He sampled rocks from the Tsangpo suture zone and the north slopes of Mt. Everest. The trip across the Himalayan Range and down the Dud Khosi River to Kathmandu gave a cross-sectional view of the metamorphic rocks of the core of the Himalayas.

In a collaborative study with Drs. Peter F. Lonsdale, J. Douglas Macdougall, and Robert R. Hessler, Dr. Hawkins used the research submersible *Alvin* to sample and survey the axial region of the Mariana Trough near Saipan. The dives and rock dredging yielded an extensive suite of samples from along the spreading axis of the back-arc basin. The rocks included basalt typical of mid-ocean ridges, and highly evolved, silica-rich rocks. The researchers also looked for hydrothermal circulation and vent systems. On the previous leg of this expedition, Dr. Harmon Craig had located three vent fields; Dr. Hawkins and colleagues located a fourth field and extensively sampled and surveyed all of the vents. The Mariana Trough vents form highly irregular structures one or two meters high, with concentric zones of amorphous silica, barite, and zinc, copper, iron, and lead sulfides. Samples were collected from active vents that had shimmering hot water streaming from open tubes and spongelike masses. In addition to the sulfide masses and chimneys, there were large mounds, up to 3 m, of friable amorphous silica, barite, and iron oxide. The vent systems had extensive colonies of crabs, shrimp, gastropods, and anemones. The mineralogy and structure of the Mariana Trough sulfide chimneys are almost identical to samples collected by Dr. Hawkins in the Lau Basin on Papa-Tua Expedition in 1986. The Lau Basin

vent material, the first to be found in a back-arc basin, has been matched by subsequent discoveries in the Woodlark Basin, at two other sites in the Lau Basin, and the four sites in the Mariana Trough. Back-arc basins are thus as important as mid-ocean ridges as sites where hydrothermal circulation forms metalliferous sulfides.

Drs. Devendra Lal and Edward L. Winterer, with other colleagues, had previously demonstrated the feasibility of using a nuclear method to determine the natural erosion rates of rock surfaces. The method is based on in situ cosmic ray production of ^{10}Be (half-life, 1.6 m.y.) and ^{26}Al (half-life, 0.7 m.y.) in quartz that is fairly ubiquitous. To determine the production rates of these isotopes, the researchers studied their concentrations in several glacially polished granitic rocks from the Sierra Nevada, which have known exposure times. In addition to yielding isotope production rates, these measurements have firmly established the nuclear method for determining erosion.

In other collaborative work on cosmic ray-produced nuclides, the scientists found a fairly high concentration of ^{10}Be in a conglomerate industrial diamond sample from Zaire. The ^{10}Be activity can be shown to arise from nuclear interactions of cosmic rays in the diamond grains during their residence in the top few meters of the alluvium. This leads to the conclusion that at least 29% of the ^3He in the Zaire diamonds derives from in situ cosmogenic production. Thus high $^3\text{He}/^4\text{He}$ ratios reported in some diamonds may indeed be cosmogenic, and not of solar wind origin, as has been hypothesized.

Dr. Macdougall and colleagues in the isotope geology and geochronology laboratory investigated magma generation processes at mid-ocean ridges by using short-lived radiogenic isotopes from the uranium decay series. They also used long-lived radiogenic isotopes (of elements such as strontium and neo-

dymium) to study the chemical makeup of the earth's mantle under the continents and oceans. Graduate student Kenneth H. Rubin has discovered "excess" ^{226}Ra in fresh basalts from the East Pacific Rise, which implies that very-small-degree partial melts of the mantle are separated from their sources, mixed with other melts, and transported rapidly to the surface. Using the daughter isotopes of longer-lived radioactive species, graduate student Qun Cheng has determined that the source region in the earth's mantle for the Louisville Seamount Chain (a major bathymetric feature in the southern Pacific Ocean) has remained distinct from the source for ocean ridge basalts for over 100 million years. His finding relates to the way in which mantle plumes operate, and to the convective regime in the mantle. Graduate student Alan M. Volpe has been comparing basalts sampled from the marginal basins of the western Pacific with possible ancient analogs found in an ophiolite terrane in Rajasthan, India. Volpe, Dr. Macdougall and an Indian graduate student made a second expedition to the Phulad ophiolite complex and completed detailed sampling. Preliminary chemical data hint at many similarities to modern island-arc environments.

During the same expedition, Dr. Macdougall and colleagues visited and sampled basalts and mantle-derived xenoliths from alkali volcanoes in Kutch, in western India. These volcanoes are thought to be related to the Deccan flood basalt episode, and their included xenoliths thus clarify the sub-Deccan lithosphere. Preliminary data indicate that the alkali basalts are isotopically similar to the Deccan tholeiites, but that the xenoliths are quite distinct, and preserve the isotopic signature of an old, depleted lithosphere that has recently been overprinted by interaction with an enriched component.

Dr. James H. Natland continued his studies of Indian Ocean basaltic and gabbroic rocks in collaboration with

Dr. Robert L. Fisher and colleagues. Their work explores the relationship between the lava composition and the crystalline assemblages that precipitated from similar melts in magma chambers. The researchers have also mapped differences in basaltic compositions in various parts of the Indian Ocean. The studies show that abrupt differences in basalt compositions occur at major tectonic features of Indian Ocean ridges, and that there are important consequences in the mineralogy of the gabbroic crystalline cumulates.

Dr. Natland also spent several months on a collaborative study of more than 150 dredge hauls from the East Pacific Rise. Dr. Natland focused on offsets of the rise axis, using samples dredged from four such features that were also studied using Deep-Tow. The petrological data confirm that these offsets represent significant geochemical discontinuities along the rise axis, consistent with interpretations that the rise is supplied with basaltic material from discrete regions of partial melting in the mantle. The data also confirm that such regions differ from each other in thermal structure and source characteristics. The study thus elucidates the scale of melting domains that supply volcanic features at this spreading center.

Dr. Natland participated in a combined geophysical and dredging survey of a major island chain in the Pacific—the Marquesas in French Polynesia. The shipboard survey showed the islands to be comparatively steep volcanic structures atop broader domes, constituting the largest volume of volcanic material in the chain. The domes had been described as archeipelagic aprons by the late Dr. H. William Menard, who

nevertheless considered that they were largely volcanic in origin. The present survey—a combination of high-resolution bathymetry (Sea Beam), gravity, and seismic-reflection profiling—confirmed Dr. Menard's conclusion and showed these structures to be thinly sedimented and studded with small volcanic cones. The structures are a major submarine expression of ocean-island volcanism, and have never before been sampled in an island chain. The expedition to the Marquesas is the first integrated survey of such features, and opens a new dimension in the submarine volcanology of major chains in the ocean basins.

Dr. Lisa Tauxe and the paleomagnetic group are studying the magnetic records preserved in rocks. These records may yield information on the age of rock formations, the history of tectonic displacements, and details of geomagnetic field behavior on time scales heretofore inaccessible. To fully use the paleomagnetic record, scientists must clarify rock magnetization and the reliability of that magnetization. Dr. Tauxe and associates investigate the properties of various magnetization processes, and apply paleomagnetic techniques to problems in stratigraphy and geomagnetic field behavior.

Dr. Tauxe and graduate student Laura A. Stokking continued research on chemical remanent magnetization—the magnetization acquired by growth and alteration of magnetic minerals. Dr. Tauxe and graduate student Jeffery S. Gee began an empirical study of the magnetic properties of seamount rocks. They hope to provide constraints for interpreting the magnetic anomalies associated with seamounts.

The paleomagnetic group uses the techniques of magnetostratigraphy for several research projects. Dr. Tauxe and David R. Clark completed a study of the age of Paleogene sedi-

ments in the Canadian Arctic. Previous studies had suggested that the ages of flora and fauna in the Arctic and the ages of similar forms in the southwestern United States differed by up to 18 m.y., a result not anticipated from theory or observations elsewhere. The paleomagnetic group's results call into question the data underlying the proposed time difference. The new data are compatible with an interpretation of no temporal difference between the Arctic and the Southwest Paleogene.

Graduate student Juan C. Herguera is studying magnetostratigraphy and biostratigraphy in the Miocene marls of Spain. He hopes to improve the resolution of correlations between the time scale based on biotic evolution and that based on geomagnetic polarity reversals. Other magnetostratigraphic studies include the sediments of the East African Rift and deep-sea sediments recovered during leg 108 of the Ocean Drilling Program.

Dr. Tauxe's studies concerning the behavior of the geomagnetic field include a collaborative effort to investigate the behavior of the earth's magnetic field during reversal. Studies are focused on several records collected from sediments of the ancient Lake Tecopa (just east of Death Valley) and deep-sea sediments cored during leg 108 of the Ocean Drilling Program.

Drs. Catherine G. Constable and Tauxe showed that the sediments of the Ontong-Java Plateau retain a reliable record of long-term variations in the geomagnetic field intensity. The results from box cores taken during the Eurydice Expedition compared well with those from nearby Australian lakes and the Australian archeomagnetic record.

MARINE BIOLOGY RESEARCH DIVISION

Marine Biology Research Division scientists continue to investigate the biochemical, physiological, ecological, and behavioral characteristics of marine animals, plants, and bacteria. Their studies range from the transport of nutrients between surface waters and the deep sea to the homing behavior of pelagic sharks.

Dr. Horst Felbeck's group investigated the symbioses between chemoautotrophic bacteria and invertebrates. Graduate student Jeffrey L. Stein researched the nitrogen assimilation pathways in several symbiotic systems, including that of mussels and methane-oxidizing bacteria. In his study of symbiosis, graduate student Daniel L. Distel used radiotracer techniques to describe the metabolic interactions between the clam *Lucinoma aequizonata* and bacteria. He also characterized a variety of symbiotic bacteria by sequencing their ribosomal 16S RNA. Graduate student S. Craig Cary described and measured the natural environment of *L. aequizonata* and analyzed this clam's quantitative nutritional requirements.

How ultraviolet screens affect photoadaptation of bloom-forming phytoplankters is a research focus in Dr. Francis T. Haxo's laboratory. In the case of the cyanobacterium *Oscillatoria (Trichodesmium) thiebautii*, the prominent ultraviolet absorbing compounds occurring in bloom collections were absent in a laboratory isolate of *O. thiebautii* grown under low light conditions. With Drs. Maria Vernet and Amir Neori, Dr. Haxo showed that strong ultraviolet ab-

sorption, possibly attributable to different molecules, is characteristic of red tide collections of the dinoflagellates *Prorocentrum micans* and *Gonyaulax polyedra*. Strong ultraviolet absorbance is a persistent feature of *G. polyedra* in laboratory culture. Dr. Haxo's group is making a comparative study of how irradiance level affects the biosynthesis of such molecules during growth.

Dr. Mark E. Huntley led the first portion of the Antarctic expedition RACER (Research on Antarctic Coastal Ecosystem Rates). Scientists focused on the processes that cause extraordinarily high biological productivity in the Antarctic Peninsula region. Drs. Huntley and Edward Brinton found egg-bearing Antarctic krill females (*Euphausia superba*) down to 1,800 m (tripling the known depth range) and recorded the highest known larval development rates per day. They discovered what may be a major nursery area for this species. Results of this multinational expedition have produced dramatic changes in our understanding of Antarctic productivity.

Dr. Huntley and Dr. Victor H. Marin completed a southern California water study demonstrating that grazing marine zooplankton can change the optical clarity of seawater (diffuse attenuation coefficient) by as much as 50% per day. Working with three graduate students, Dr. Huntley completed a study on the nutrition and development of larval copepods and northern anchovy (*Engraulis mordax*) and demonstrated that differences in food quality markedly affect growth and survival.

Dr. A. Peter Klimley and graduate student Steve B. Butler continued investigating orientation/navigation mechanisms in pelagic sharks. The homing behavior of the scalloped hammerhead shark was studied during a month-long cruise aboard R/V *Robert Gordon Sproul*. These sharks home to seamount El Bajo Espiritu Santo in the Gulf of California. Data were gathered throughout the shark's nocturnal movement into the pelagic environment as far as 20 km from the seamount. Instantaneous swimming directions, depths, surrounding water temperatures, and irradiance levels were telemetered and computer-decoded. A high degree of swimming directionality was recorded even at great distances from the daytime habitat. The shark's return followed its outward path despite strong crosswise currents, indicating that these open-ocean migrators may be able to compensate for ocean current drift. Environmental features that may be used as orientational aids were measured. Currents and temperatures were recorded during tracking, and local bottom topography and geomagnetic fields were mapped from previous Scripps cruise data. Although the sharks' paths were found to lie parallel/antiparallel to isocontours along a geomagnetic anomaly gradient (probably from a geomagnetic reversal lineation), proof of this relationship awaits further studies.

In another study, 18 sharks were tagged with coded pingers and then tracked for 10 days by microprocessor-based monitors deployed at dif-

Waldo Wakefield uses an electronic digitizer to count benthic megafauna from photographic transects taken on the continental slope off central California. Two MBRD laboratories joined forces to develop the deep-sea camera sled used to take the photos, and the system for analyzing them.

ferent sites at the seamount. Tagged sharks exhibited extreme site specificity in their daytime schooling.

Researchers in Dr. Kenneth L. Smith's laboratory study the ecological energetics of deep-sea communities. Dr. Smith and two colleagues are analyzing active and passive transport of organic carbon at abyssopelagic and mesopelagic depths. Free-vehicle acoustical instruments have yielded insight into animal migrations in the deep sea. Vertically migrating animals convey organic matter through the water column at abyssal depths. Researchers are analyzing active transport at shallower mesopelagic depths where diel vertical migrations predominate, amplifying the importance of active transport in carbon cycling. Graduate student W. Waldo Wakefield continues to study how planktrophic development of slope-dwelling demersal species affects the transport of organic matter through the water column. The frequently ignored upward flux of lipid-rich eggs and larvae of abyssal species may be an important component of the total flux of organic matter. Another graduate student, Ronald S. Kaufmann, is studying the sensory biology of deep-sea scavenging amphipods, important components in the active transport of organic matter at abyssal depths. He identified both chemoreceptive and mechanoreceptive structures on these amphipods. Studies of seamount biology continued from a submersible in the central and western North Pacific. In collaboration with Dr. Amatzia Genin, Dr. Smith's group has analyzed how physical parameters affect the functional ecology of soft substrate communities from bathyal to abyssal depths.

Research in Dr. George N. Somero's laboratory focused on how organisms alter their biochemistry to adapt to the environment. Dr. Susan J. Roberts examined factors that influence protein organization within muscle cells. She found that the enzymes supplying energy for muscle contraction are reversibly bound to filaments causing contraction. The

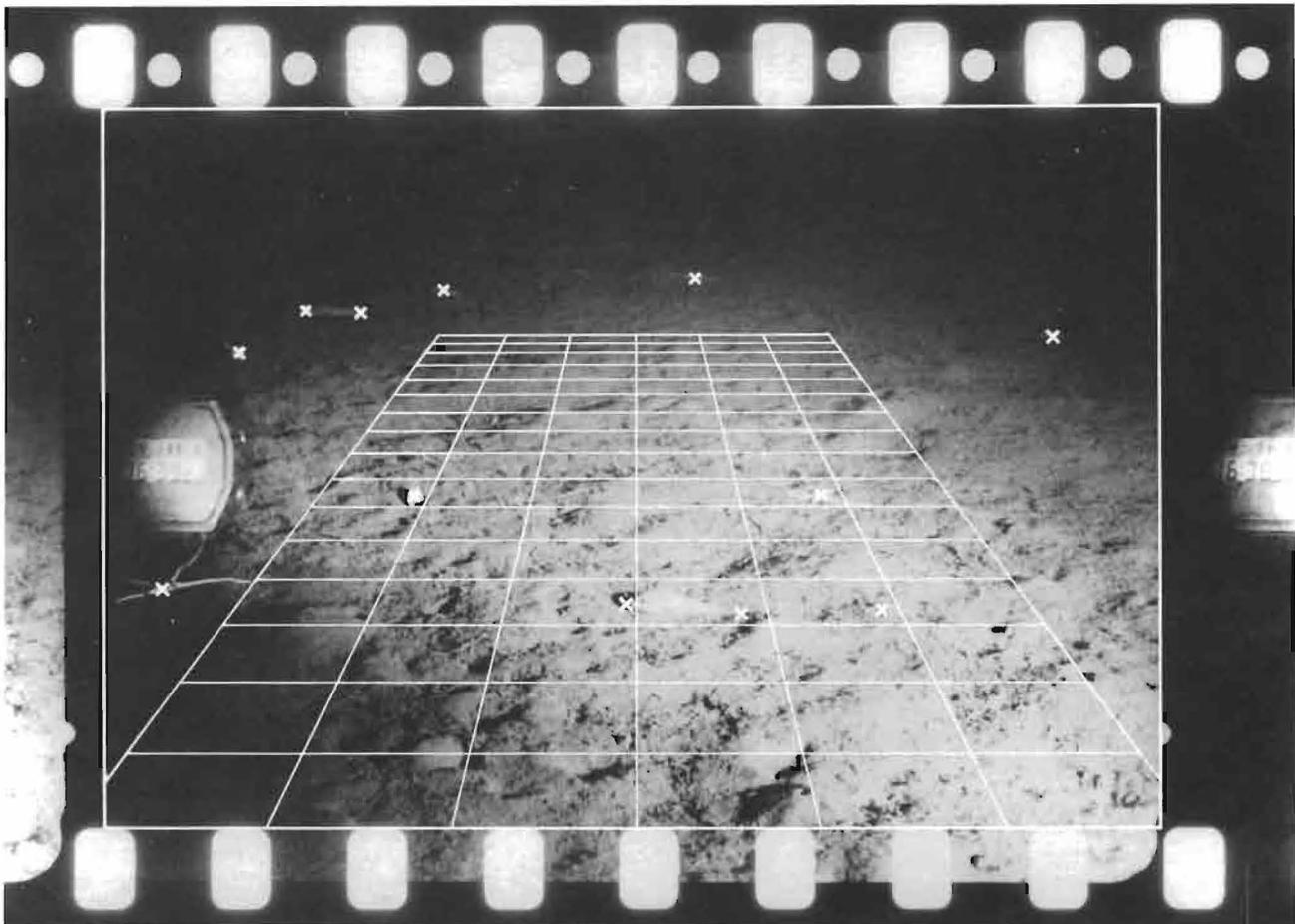


binding of enzymes to muscle filaments is affected by a number of physiological conditions, including muscle acidification during heavy exercise. Graduate student Mary Sue Lowery examined the dynamics of protein turnover in fish muscle. Her work showed that fish protein turnover is specifically affected by starvation. The enzymes supplying power for muscle contraction decreased rapidly in activity during starvation. Lowery and Dr. Roberts showed that starvation also leads to the release of bound enzymes from muscle filaments. Graduate student Sandor E. Kaupp examined developmental changes in muscle enzymes. He found all fish larvae in his study to be very similar in metabolic capacity through a certain stage of development; after this stage, broad interspecific differences related to the fish's ecology and swimming mode arose.

Dr. Zulema Coppes studied how fish muscle enzymes adapt to temperature. Graduate student Mark A. Powell examined the methods animals from sulfide-rich environments (e.g., deep-sea hydrothermal vents) use to avoid poisoning and to exploit sulfide's energy. He found a variety of mechanisms, including sulfide oxidation by animal mitochondria, with the concomitant production of adenosine triphosphate (ATP). This was the first demonstration that an animal can gain energy by oxidizing an inorganic energy source (sulfide). Graduate student Allen G. Gibbs continued to study how hydrostatic pressure affects an enzyme system responsible for ion regulation in fishes. The responses of this enzyme system to high pressure differ significantly in deep- and shallow-living fishes, indicating that adaptation to depth involves adjustments in the properties of ion-transport enzymes.

Photograph from a transect showing the continental slope environment and some common megafauna off Point Sur, California. These photo transects are used to study the spatial distribution of animals inhabiting the slope. The perspective grid indicates scale (20-cm grid squares) in this oblique photograph.

W. Wakefield



Dr. Joan G. Stewart has prepared an annotated checklist of the intertidal and subtidal benthic marine algae of San Diego County to help researchers identify morphological forms and locate specimens in near-shore habitats. She completed a study of processes that maintain two dominant vegetation forms (coral-line-anchored algal turf and *Phyllospadix* mat) on the intertidal, rock platform beaches of southern California.

Using recombinant DNA techniques, Dr. Frederick I. Tsuji reengineered the aequorin molecule, a calcium-binding protein found in the jellyfish *Aequorea victoria*. Aequorin consists of a chromophore bound to a chain of 189 amino acid residues. Light is emitted when aequorin is mixed with a trace amount of calcium. A series of aequorin molecules has been constructed in which a sin-

gle amino acid residue has been substituted by another. How the molecule produces light may be understood by studying the ways that modifications affect light emission.

Dr. Victor D. Vacquier's group studies the biochemistry of sea urchin fertilization. Principal interest is in the proteins of the sperm plasma membrane: How do they regulate the sperm activation that occurs when sperm meets the egg? The group also studies the phosphorylation of histones in the sperm, a process that depends on protein kinase activity in both sperm and egg. This basic knowledge about the fertilization process in one marine invertebrate will increase the general knowledge of fertilization in animals.

Dr. Benjamin E. Volcani's group continues to study how silicon regulates (1) gene expression and DNA replication, and (2) cAMP metabo-

lism in the diatom *Cylindrotheca fusiformis*. Two diatom plasmids in the bacterium *E. coli* were cloned. This cloning allows the insertion of an antibiotic-resistance marker gene that is controlled by a promoter, thus permitting the development of a diatom transformation system. With two UCSD colleagues, the group began a study on oncogene homologues in the diatom. Southern analysis revealed DNA sequences hybridizing to yeast RAS 2 (associated with cAMP metabolism) and mouse c-myc oncogenes. Dr. Paul P.-C. Lin found that the diatom contains at least three cAMP-dependent protein kinases, distinguished by their physicochemical properties. How silicon affects their activities is being studied.

MARINE LIFE RESEARCH GROUP

Scientists in the Marine Life Research Group (MLRG) investigate the physical, chemical, meteorological, and biological milieu in which many economically important species of plants and animals live. MLRG scientists frequently work with scientists from the Southwest Fisheries Center, National Marine Fisheries Service, and the California Department of Fish and Game (California Cooperative Oceanic Fisheries Investigations) to study the life histories and population biology of various species. Together these three agencies have embarked on eleven research cruises during the past year to assess the status of the marine environment and fisheries stocks of the state of California and its adjacent waters.

One notable observation has been a gradual increase in abundance of the Pacific sardine, a mainstay of the California fishing economy before its decline in the 1940s and 1950s. Continued study of the factors accompanying both the decline and the recovery of this sardine is important to the informed management of many other species. Researchers find that global, interannual, climatic episodes and cycles are at least as important as fishing pressure in regulating these populations, because the California Current system responds dramatically to global forcing factors. Many MLRG scientists are studying large-scale and mesoscale processes in the sea.

Orbital satellites are used by MLRG researchers to obtain detailed images of the ocean surface off the

coasts of the Californias, and to track instruments deployed in ocean currents. Images generated by Drs. José Peláez and John A. McGowan have resulted in an improved understanding of the eddies, filaments, and frontal systems that characterize the California Current.

Dr. Mark R. Abbott used satellite imagery of sea-surface temperature and near-surface phytoplankton pigment concentrations to study biological and physical processes in large filaments in the California Current system. These filaments recur at certain coastal headlands, primarily during the upwelling season (March–September). The filaments appear first off the central California coast and then farther north (Washington–Oregon) as the region of upwelling-favorable winds moves north. Preliminary examination of satellite imagery from 1980 and 1981 indicates that local winds and sea level affect filament length: when winds are strong and sea level anomalously low, filaments are longer.

More than 50 satellite-tracked drifters were launched in the California Current system by Dr. Pearn P. Niiler in the last two years. The drifters follow water parcels to an accuracy of 2 cm/sec during their 9-12-month lives. These drifters have contributed to a revised picture of the California Current in which the filaments flow rapidly southward between active mesoscale eddies. This eddy activity is stronger than the mean flow. Horizontal mixing caused by these eddies spreads water parcels east and west at rates about half that of the mean southward flow rate. A theoretical,

numerical hydrodynamic model of the Eastern Pacific has been developed that qualitatively explains the observed distributions at a mesoscale range.

This mixing affects the distribution of nutrients in the water, which in turn affects primary production. Dr. Thomas L. Hayward is studying the physical processes that influence the rate at which nutrients are supplied to the euphotic zone. Data obtained from the California Cooperative Oceanic Fisheries Investigations cruises have been used to describe seasonal and large-scale patterns of primary productivity in the California Current. Additional field work along the coast of central and northern California has clarified the interrelation of biological patterns and physical structure.

Dr. Ann C. Bucklin has been using allozymes (genetic markers) to trace dispersal patterns of zooplankton in filaments along the West Coast. Allozymic markers indicated that zooplankton are transported through the filament along paths of geostrophic flow. The genetic similarity of samples relates strongly to their position in the flow field and the geographic source of the population, and not to the distance between samples. The observed patterns of gene flow were concordant with transport expected from physical models of vertically migrating particles, affirming allozymes' utility as markers for examining zooplankton dispersal.

Dr. James J. Simpson is involved in developing systems to produce integrated four-dimensional representa-

Dr. Elizabeth L. Venrick filters seawater. Subsequently, chlorophyll will be extracted from the phytoplankton retained on the filter. The concentration of chlorophyll is used as a measure of phytoplankton biomass.



tions of the oceanic environment in real time. He generates numerical models of the oceanic environment by using a network of computer nodes to perform image analysis of data collected by orbital satellites and to integrate ground-truth data such as temperature, sound velocity, and chlorophyll concentration.

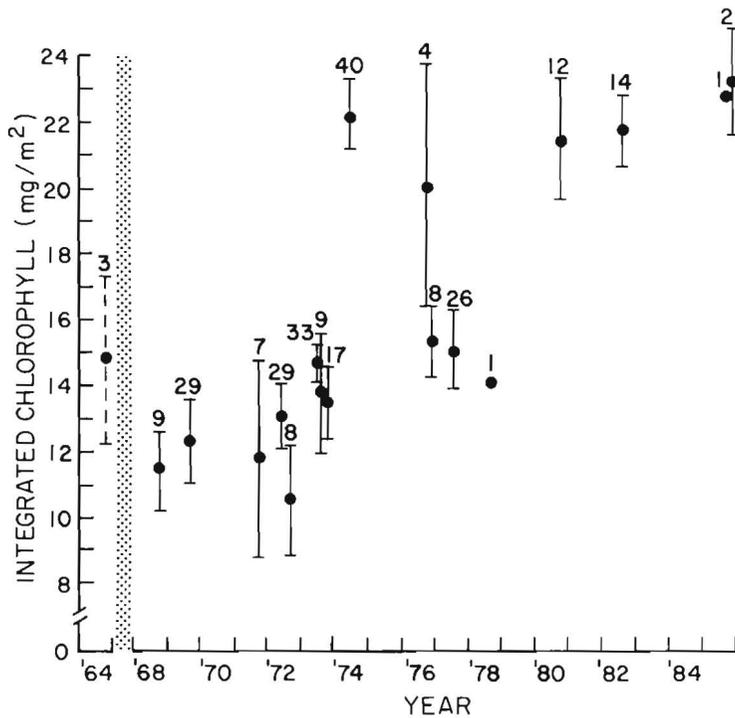
Dr. Loren R. Haury is studying the physical and biological factors that determine the vertical and horizontal distribution of zooplankton on scales of meters to kilometers. One just-completed study examined the vertical distributions of six species of *Pleuromamma* copepods across the eastern North Pacific Ocean. Distributions of co-occurring species overlapped considerably at night when they were feeding in the surface layers. This shows that closely related,

morphometrically similar species do not minimize competition for food by separating vertically, as some theories have suggested.

Andrew Soutar's work on biogenic sediments of anaerobic basins in the California Current region has revealed that the Santa Monica Basin has an annual varve record that begins about 1850, and is well developed from 1900 to the present. This record may provide new insights into the population structures of commercially important fishes. The record may also facilitate cross-calibration of varved sediment cores taken from other basins in the region. With a researcher from Mexico, Soutar has investigated the recent history of warm-cold events as reflected in the varved sediments of the Guaymas Basin, and discovered dramatic signs of El Niño episodes.

Drs. Niiler and Melinda M. Hall have collected the longest continuous time series of ocean circulation data ever obtained from the eastern Pacific Ocean. The 40-month-long current-meter deployment at 28°N, 152°W and at 42°N, 152°W revealed mesoscale eddies at the former location but not at the latter (where overall energy levels are much lower). The researchers interpreted this to mean that the potential energy stored in the tilt of the main ocean thermocline, derived from low-frequency shear, is released at 28°N to form mid-ocean eddies. These measurements are the first experimental confirmations of a phenomenon that was predicted 20 years ago.

Drs. Elizabeth L. Venrick, McGowan, and Hayward described a long-term biological change in a



Graph shows the chlorophyll increase in waters north of Hawaii between 1963 and 1985. Bars indicate the 95% confidence intervals around the means; the number of observations is shown above each bar. E. Venrick

mid-ocean ecosystem. They have discovered a significant increase in chlorophyll between 1963 and 1985 in a region north of Hawaii (28°N, 155°W) that was thought to be ecologically stable. In collaboration with Daniel R. Cayan, the researchers have correlated this increase in chlorophyll with an increase in the strength of winter winds during the same period. The researchers postulate that the vertical transport of nutrients into the euphotic zone is increased by the strengthened winds, resulting in an enhanced carrying capacity for the ecosystem.

Dr. Dean H. Roemmich and a colleague have compiled a comprehensive set of modern, deep hydrographic sections, including data collected by many different investigators, spanning the North Pacific Ocean. These data, together with accompanying direct measurements of ocean currents from current-meter moorings and acoustic Doppler current profilers, were

used to estimate large-scale ocean circulation from the surface to the bottom, and the transport of heat in the North Pacific. In a related study, Dr. Roemmich and two colleagues examined heat transport across 24°N. They found that the ocean carries 0.85×10^{15} watts northward across 24°N in the Pacific. When these observations were combined with earlier work on the North Atlantic, it was found that the global ocean carries 2×10^{15} watts across 24°N. This means that, in maintaining global climate, the ocean carries a greater amount of excess heat away from the tropics across this latitude than does the atmosphere.

Dr. Abraham Fleminger has been investigating how "tramp" species of copepods are introduced to, and influence exotic habitats. One example is a bay-dwelling copepod native to the west coast of Japan, *Pseudodiaptomus marinus*, which has been found recently in Mission Bay, San Diego, and Agua Hedionda Lagoon, Carlsbad, California. It is unlikely that

these exotics came from ballast water, because neither body of water is deep enough to admit transoceanic shipping. Dr. Fleminger therefore proposes that this exotic copepod accompanied transfers of oyster stock from Japan to California aquaculture enterprises. Preliminary evidence suggests that the local congener may be displaced by this exotic species.

Dr. Edward Brinton has been examining the maturation rates and morphology of Pacific and Antarctic euphausiid crustaceans (krill). A newly discovered, particularly large species, *Thysanopoda minyops*, caught in the abyssal North Pacific by Dr. Kenneth L. Smith, was found to possess minute eyes but greatly enlarged crystalline cones. This prompted a study of eye size in relation to developmental stage in a group of giant (to 15 cm) *Thysanopoda* species, the deeper-living of which lack the photophores common in euphausiids. Species living above 2,000 m differ from the deeper species in that they undergo reversals in eye size during the course of development. Eye size increased rapidly during the part of larval life spent at relatively shallow depths (300–500 m), then decreased rapidly during ontogenetic descent to 500 or 1,000 m in late larval life. Eye size increased again during maturation in the bathypelagic zone. Reversal in eye growth has not been noted before in crustaceans and raises questions about the relative roles of ambient light and bioluminescence in inducing such adaptations.

Joseph L. Reid and two colleagues are analyzing data from a 1982 expedition to the North Atlantic. They studied the nature of the deep overturn that can occur there in winter, and the exchange of waters between the Greenland Sea and the Arctic Ocean. These data reveal that the upper layers were less saline in 1982 than in 1958 by about 0.078 parts per thousand. As a result, the surface waters were less dense than in 1958, making overturn or deep convection less likely.

MARINE PHYSICAL LABORATORY



Dr. Fred N. Spiess examines Deep Tow maps and side-looking sonar images of the West Florida Escarpment.

Scientists at the Marine Physical Laboratory (MPL), directed by Dr. Kenneth M. Watson, study underwater acoustics, with related seawater chemistry and signal processing; ocean dynamics; seafloor geology and geophysics; and the ocean technology required to support their studies.

Dr. Fred N. Spiess's Deep Tow group participated in an ocean engineering expedition to locate a route for a major power cable across the steep, rugged seafloor of Hawaii's Alenuihaha Channel. The group made profiles with resolutions

smaller than a meter and meter-level navigation along tracks chosen from imagery interpretations taken from a high-resolution, near-bottom, side-looking sonar (SLS). Their objectives were met, and Dr. Carl D. Lowenstein implemented the SLS image-processing capabilities to produce mosaics depicting the slopes of the channel from depths of 700 m down to its deepest point at 2,000 m.

On another expedition, Dr. Spiess's group investigated the geology of the West Florida Escarpment, a 2,500-m-high cliff incised with 3,000-m-deep box canyons—the same

depth as the adjacent Gulf of Mexico. In collaboration with Dr. Charles K. Paull, the group focused on the cliff base, charting morphology and identifying seeps that apparently undermine it, giving rise to its steepness and supporting dense biological communities.

The Deep Tow group introduced a new vehicle—a thruster-propelled device suspended on electromechanical cable (18 mm in diameter)—that can maneuver into complex terrain to place or recover seafloor devices. The vehicle can telemetrically support other equipment to be operated

Crew aboard R/V Melville launches Deep Tow.

MPL



on or below it, and it carries a slow-scan TV, a scanning sonar, and a transponder. It was used during the West Florida Escarpment expedition to take photographs close against the cliff base.

Several projects in underwater acoustics and signal processing were directed by Dr. William S. Hodgkiss. The system control and quick look/calibration analysis software for a high-speed data recording system was upgraded and is being used to collect data in a series of flow noise studies.

In another research area, Dr. Hodgkiss's Swallow float array for measuring low-frequency ambient ocean noise was fabricated and deployed. Although the Swallow floats are freely drifting, each buoy transmits on schedule, emitting a localization signal that is received by the other buoys. Knowing the locations of all elements makes it possible to assess the directionality of the ambient noise field.

A major, very-low-frequency ambient noise experiment was conducted off southern California at 32°

37'N, 120° 33'W in 3,700 m of water southeast of the San Juan Seamount. The sensors deployed during the experiment included 12 Swallow floats, 8 sonobuoys supplied by the naval Air Development Center, and 13 ocean-bottom seismographs. Researchers will use the resulting data to describe the temporal and spatial characteristics of ambient noise; they will relate these characteristics to



Computer image of the Blanco Trough recorded by Deep Tow. C. Lowenstein

weather, sea-surface conditions, and shipping traffic.

Dr. Fred H. Fisher's group took two sea trips to measure the vertical correlation between direct and surface-reflected paths for narrow-band and broad-band signals. For these measurements, the group used the low-drag, 64-element vertical array they developed.

A gravity meter for measurements on the deep seafloor and in the mid-water column was constructed by Dr. John A. Hildebrand, in collaboration with Dr. Spiess. They adapted a La Coste and Romberg gravity meter contained in a pressure case, along with a leveling unit and associated electronics for telemetry and control. Researchers conducted initial field tests of the deep-sea gravity meter; they now plan to use it to observe short wavelength components of the oceanic gravity field and to determine the structure of geological features in the upper few kilometers of the oceanic crust.

Drs. LeRoy M. Dorman and Hildebrand, and graduate student Allan W. Sauter and others emplaced 13

ocean-bottom seismographs on the seafloor in a two-dimensional array about 300 km west of San Diego in water 3,800 m deep to study the spatial organization of seafloor noise. Seafloor sediments are characterized by very low shear strength, so interface waves trapped at the seafloor travel at velocities as low as 50 m/s (in contrast with approximately 1,000 m/s on land). This low-velocity propagation is accompanied by correspondingly short wavelengths, requiring close instrument spacing to avoid spatial aliasing. The minimum array spacing was 10 m; to obtain positioning accuracy of 2 m (at the end of a 3,800-m wire), Dr. Spiess and a colleague used a thruster to maneuver the end of the wire under transponder navigation. The maximum element spacing was 160 m. From preliminary examination, at 50-m separation, coherence between vertical seismometers is high from 0.15 Hz to 5 Hz. Although coherence between the vertical seismometer and hydrophone does not extend that high in frequency, there is high coherence at .05 Hz.

Dr. Spahr C. Webb designed a new instrument for geophysical studies and constructed two prototypes. The instruments, deployed off of the Washington coast as part of a small seismic experiment, carry differential pressure gauges. One also carries two transducers to measure the local horizontal gradient of pressure. In this work Dr. Webb continues an effort to measure and describe the seismic and oceanographic signals seen at very low frequency (below 1 Hz) at the seabed. Pressure fluctuations at frequencies below about .03 Hz in the deep ocean are caused by long gravity waves on the ocean surface. Two major objectives of the studies at these frequencies were to identify source regions and estimate the reflection coefficient at a coastline. At slightly higher frequencies (.03–1 Hz) the pressure spectrum is much quieter, and the origin of the signal in this band is still obscure, but seafloor turbulence is the mechanism under study in the most recent experiments. Energy in the "micro-

seism" band (.1–5 Hz) is clearly derived from interactions of waves on the ocean surface.

Dr. Andrew G. Dickson is directing a study of acid-base chemistry in seawater, and of the thermodynamics of boron, magnesium, aluminum, and silicon hydrolysis in aqueous electrolyte solutions at various temperatures. He finished a highly accurate (± 0.003 in pK) set of measurements of the first dissociation constant of carbonic acid in seawater over a wide range of salinity ($S = 5 - 45$) and temperature $0^\circ - 45^\circ\text{C}$). These data are part of a series of measurements of the dissociation constants in seawater media. This high degree of accuracy is needed to ascertain the internal consistency of various sets of field measurements (alkalinity, total inorganic carbon, and P_{CO_2}) in the CO_2 system and to calculate the so-called buffer factor for modeling purposes.

Dr. Robert Pinkel's Upper Ocean Physics Group investigated the dynamics of motions in the top kilometer of the ocean, including surface waves, mixed layer development, and internal waves. The group participated in a five-week expedition (PATCHEX) 500 km off the central California coast. Data from this and several other cruises are being analyzed. Graduate student Jeffery T. Sherman is developing a coherent Doppler sonar system for small-scale shear measurement in the thermocline. PATCHEX data collected with this instrument are being analyzed and compared with data from profiling CTDs and the incoherent Doppler sonar system that measures larger-scale motions. Shear profiles with 1-m resolution were obtained to a range of 30 m with the new coherent sonar.

Dr. Jerome A. Smith is analyzing data from PATCHEX and previous experiments taken with sonars that scatter off the underside of the sea surface. The surface-scattering sonars can resolve surface waves longer than about 70 m, with sufficient coverage to produce three-dimensional frequency-wavenumber spectra. The same sonars also resolve low-frequency currents, such as Langmuir

circulation, in the mixed layer. These data are being used to explore the development of both the wavefield and upper ocean mixing as functions of wind, heating, and other environmental effects.

Dr. Pinkel's motion analysis of the upper thermocline now emphasizes the comparison of fine-scale (10-100 m) shear and strain, as measured with Doppler sonars and CTD profilers. Linear internal wave theory appears to describe the shear-strain relationship well at vertical scales greater than 30 m.

In the last six years seafloor survey techniques have been revolutionized by multi-narrow-beam echo sounders and improvements in navigation accuracy (tens of meters). This technology can be directly transferred to ocean-volume reverberation measurements: it offers both the high volume coverage and high resolution necessary to study the patchiness of biological scatterers in the deep ocean. To explore this application, Drs. Christian de Moustier and Dimitri Alexandrou measured 12-kHz volume reverberation in the oceanic deep scattering layers using the multibeam echo sounder Sea Beam and a special-purpose, acoustic data-acquisition system designed at MPL. They will produce horizontal and vertical contours of backscattered acoustic intensity in the scattering layers to give clues to local patchiness in the distribution of mesopelagic organisms responsible for acoustic scattering at 12 kHz.

On a recent cruise, Drs. de Moustier and Peter F. Lonsdale used Sea Beam high-resolution swath bathymetry and seismic profiling to survey the submerged section of the east rift zone of the Kilauea volcano (Hawaii). Dr. de Moustier used his acoustic data-acquisition system to measure the relative strengths of bottom backscattered signals received by Sea Beam over seafloors with contrasting roughness. These measurements support his efforts to acoustically identify bottom types with multi-beam echo sounders, complementing their purely bathymetric function.

NEUROBIOLOGY UNIT



Dr. R. Glenn Northcutt, seen through an aquarium tank, prepares to study an axolotl's lateral-line sense organs.

The brain, sense organs, and the control of behavior, particularly in fish, are the focus of scientists in the Neurobiology Unit. The unit is associated with Marine Biology, the Marine Biomedical Program, and the Ocean Research Division.

Dr. Walter F. Heiligenberg and his group use electric fish to study the neural basis for processing sensory information and controlling adaptive behavioral responses, such as the "jamming avoidance response," by which each fish avoids the potentially disturbing signals of its neighbors.

Dr. Heiligenberg and colleagues use microelectrodes to locate single nerve cells in the brain. The preferences of a cell are then tested, and dyes are injected to visualize the cell's connections. In this way the researchers have worked out the circuitry in greater detail for a normal social act than for any other vertebrate behavior.

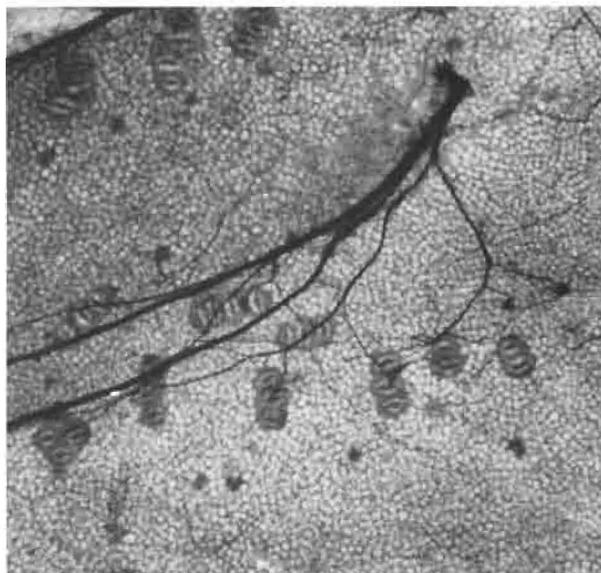
Dr. R. Glenn Northcutt and his group focus on the development and evolution of vision and the lateral-line sense organs of fishes and amphibians. Drs. Mario F. Wulliman and

A permanently aquatic salamander, the Mexican axolotl is one of the best species of amphibians for studying the lateral-line system. These animals possess lateral-line organs (neuromasts) that are sensitive to local disturbances in the surrounding water, as well as ampullary organs that are sensitive to weak electric fields generated by potential prey. Below is a surface view of the skin of an axolotl's lower jaw, stained to reveal groups of neuromasts and their innervation.



Northcutt have found large differences among species of coral reef fishes and other percomorphs.

Drs. Theodore H. Bullock and Horst Bleckmann found and characterized the lateral-line centers in the forebrain and midbrain of rays. Dr. Bleckmann and a colleague compared the best stimuli for lateral-line water-movement sensors in bony fish with several lateral-line canals. Dr. John C. Watney revealed the components of the neuromuscular system that controls near and far focusing of the eye in kelp bass.



G. Northcutt

OCEAN RESEARCH DIVISION

Within the Ocean Research Division (ORD) all major branches of oceanography are represented. This report features only a few of the research programs in each area: climate research, marine biology, marine chemistry, marine physics, and physical oceanography. Activities of the Physical and Chemical Oceanographic Data Facility are discussed in the Facilities and Collections section of this report.

Climate Research Group

The Climate Research Group scientists continue to elucidate and predict climate anomalies on time scales of months and longer.

Dr. Tim P. Barnett completed a collaborative project to define the space/time scales of climate evolution, which make it possible to predict surface-air temperatures over North America. They found that winter monthly temperatures are determined by two large-scale coherence structures in the atmosphere. One structure has to do with the El Niño/Southern Oscillation (ENSO) process; the other is a function of internal atmospheric dynamics only as it is independent of sea-surface temperature and tropical teleconnections. Dr. Barnett is examining general-circulation model (GCM) simulations to determine the physics responsible for these large-scale coherence structures in the atmosphere.

In collaboration with West German scientists, Dr. Barnett has concluded a series of GCM experiments testing a 100-year-old idea: Does successive snowfall over Eurasia affect

climate in the tropical regions of the Indian and Pacific oceans? The experiments show that large-scale global snow cover does indeed influence climate dynamics. However, the mechanisms affecting the Asian monsoon and ENSO are complex and involve all elements of the heat balance equation.

Daniel R. Cayan is studying climate variations over the North Atlantic on interannual to decadal time scales and comparing these with North Pacific variations. Observations of atmospheric pressure and sea-surface temperature over the North Pacific show that increased storminess and cooler surface temperatures across the Central North Pacific occurred from 1970 to the present, compared with the previous two decades. These climatic variations have teleconnections over North America.

Dr. Nicholas E. Graham used statistical models to predict equatorial sea-surface temperatures (SSTs). A wind field model was reasonable but missed the onset of cold and warm events, suggesting that equatorial winds alone are not responsible for El Niño. A sea-level pressure model was useful for El Niño/no El Niño predictions at leads of up to 16 months. In addition, Dr. Graham studied how SSTs affect outgoing long-wave radiation (OLR). A sharp break in the SST-OLR relation at 27.5°C suggests strong changes in large-scale tropical convection at this point.

Dr. Arthur J. Miller continued to study the Pacific Ocean rotational seiches that oscillate with periods longer than a day and that may be

strongly influenced by bathymetry. He uses his numerical solutions to explain oceanic response to fortnightly and monthly tidal forces. Dr. Miller is developing a quasi-geostrophic oceanic model of the North Pacific.

Dr. Jerome Namias is clarifying the persistence and evolution of the atmospheric circulation at time scales of months and longer. This work involves interactions of the upper ocean, as seen from surface temperature, and is being done in collaboration with Xiaojun Yuan. On a much longer time scale, Dr. Namias is using modern-day North Pacific and North Atlantic sea-surface temperature-atmosphere connections to reconstruct paleoclimate from the Pleistocene (especially the Wisconsin).

Dr. Namias also continues a series of experimental long-range weather and climate forecasts for the coterminous United States. He and Yuan are using a new quasi-geostrophic barotropic model designed by Dr. John O. Roads to study the prediction of monthly 700 mb patterns by dynamical methods that employ both high- and low-frequency components.

Dr. Roads is developing and analyzing a simple atmospheric general circulation model to study predictability at the monthly time scale. He analyzed how individual forecast days contribute to forecasts of time averages, and how several forecasts, statistically weighted, contribute to the ultimate forecast. His statistical method makes it possible to predict the reliability of the forecast.

Dr. Richard C. J. Somerville and Samuel F. Jacobellis have developed a theoretical model of cirrus cloud optical thickness feedbacks, which they applied to the CO₂ climate problem. Climate warming may be accompanied by an increase in atmospheric absolute humidity and hence in average cloud liquid water content and optical thickness. Cirrus clouds are not generally black in the infrared, so the increase in optical thickness may increase the greenhouse effect as well as the albedo. The researchers' major finding is that any positive feedback from cirrus is generally weaker than the negative feedback, which might halve the surface warming expected from increasing atmospheric concentrations of CO₂.

Marine Chemistry

Researchers in Dr. Joris M. T. M. Gieskes's laboratory continued to study hydrothermal activity in the Guaymas Basin of the Gulf of California. They are focusing on hydrothermal activity's geochemical effects on sediments and on the overlying water column. Detailed studies of the geochemistry of sediments and associated interstitial waters were made on short push cores obtained with *Alvin* in areas where *Beggiatoa* bacterial mats grow on the seafloor. In such areas fluids of hydrothermal origin flow toward the surface of the sediments, thus supplying necessary nutrients such as hydrogen sulfide and ammonium, as well as organic compounds for chemosynthetic growth. In collaboration with two colleagues, the researchers studied the formation of the world's youngest oil reservoir rock, consisting of layers of silica-cemented diatoms sandwiching heavy aromatic oils at a subbottom depth of only 8 cm.

Dr. Gieskes participated in leg 110 of the Ocean Drilling Program near the Barbados Subduction Zone Complex and made cooperative studies of interstitial water chemistry. A successful penetration of the décollement of an accretionary complex indicated that advective flow of fluids originating from deeper in the com-

plex occurs along this décollement zone as well as along major thrust faults. This information provides an excellent model for water expulsion from accreting sediments in subduction zones.

Graduate student Timothy J. Shaw continues to study the geochemistry of interstitial waters and solid phases in the sediments of the California Borderland basins. By sampling the upper 5-10 cm of sediments, he gained data on the comparative geochemistry of transition elements as a function of changing reduction-oxidation conditions, which in turn are related to the decomposition of organic carbon.

In Dr. Jeffrey L. Bada's laboratory, researchers study amino acid geochemistry and biochemistry. They focus on developing reactions such as racemization, and applying them as geo/biochronological tools. Recent investigations with a highly sensitive (10⁻¹⁵ mole) laser-based analytical system have indicated extraterrestrial amino acids in Cretaceous-Tertiary boundary sediments. The amino acid biochemical studies, concerned with in vivo aspartic acid racemization in mammalian proteins, have addressed whether this reaction has any significant role in protein turnover and degradation, and whether it is part of the overall aging mechanism in long-lived mammals. Laboratory scientists are using accelerator mass spectrometry to study bomb-derived radiocarbon in amino acids isolated from metabolically stable mammalian proteins.

Dr. D. John Faulkner's group is studying the chemical constituents of marine invertebrates. The researchers found a group of chemicals that are used by nudibranch molluscs for protection against predators, and are also powerful antifungal agents. New anti-inflammatory substances have been found in marine sponges, and one agent is scheduled for clinical trial.

Researchers in Dr. Edward D. Goldberg's laboratory continue to study the comparative geochemistry of platinum elements. Novel analyti-

cal techniques make it possible to determine extremely low concentrations of this previously elusive group of elements in seawater. Graduate student Jae Sam Yang has determined the concentrations of these elements in giant kelp, thus clarifying their comparative biogeochemistry.

Surface Current Energetics in the Equatorial Pacific Ocean

Away from continents and islands, the mean flow of surface currents in the tropics is predominantly parallel to the equator. Within 1,000 km of the equator in the Pacific Ocean, the currents alternately flow east then west in a series of narrow, shallow jets that are driven by the mean atmospheric winds at the ocean's surface. Corresponding to the mean currents is a pattern of mean water temperature that is warmer at the surface in the western Pacific than in the eastern Pacific and is warmer a few hundred kilometers off the equator than at the equator. These inter-related current and temperature patterns can be disrupted by fluctuating surface winds on time scales ranging from a few days to many years.

The most important disruptions are El Niño events, during which westward surface currents near the equator reverse direction, and eastward currents strengthen, while surface temperatures dramatically rise at the equator and in the eastern Pacific near the coasts of Central America and South America. The profound environmental and economic impacts of El Niño have focused attention on the physical causes of this phenomenon. A necessary step toward understanding El Niño is discovering how the mean current and temperature patterns are maintained during normal years in the equatorial Pacific.

Drs. Douglas S. Luther, Robert A. Knox, and Eric S. Johnson are collecting and analyzing temperature and current data from the equatorial Pacific, using new and traditional measurement techniques. They hope to explain what produces and maintains the mean and slowly varying

equatorial currents and temperatures. They demonstrated that a region between two of the equatorial jets (the South Equatorial Current and the Equatorial Undercurrent) is a strong source of energy for large-amplitude, short-period (20–30 days) fluctuations. These fluctuations retard the mean currents and weaken the north-south equatorial temperature differences. Much of the mean current energy is lost to these short-period fluctuations, which propagate downward and eastward away from the region of generation. The energy loss is balanced by energy input from the mean surface winds. Other researchers have proposed that the short-period fluctuations were generated by an instability resulting from the strong north-south gradient of the east-west currents. However, Drs. Luther, Knox, and Johnson have found that the vertical gradients of the currents probably contribute an equal amount to the instability of the current system.

The equatorial oceans support a variety of wave motions at periods from days to years, in addition to those forced by instabilities of the mean currents discussed above. Most of these oscillations share the common feature that, on average, they propagate energy only east or west. Drs. Luther and Knox, in collaboration with other scientists, are investigating the structure and propagation of many of these waves with an eye to determining their roles in modifying the mean current and temperature fields. They found the penetration depth of the north-south heat fluxes of the 20-30-day oscillations is determined by 60-90-day-period waves. These waves (which are Kelvin waves) are equatorially trapped and are generated by fluctuations of the surface winds thousands of kilometers west of where they have been observed. Drs. Luther and Knox and others have earlier hypothesized that Kelvin waves might be important in the onset of the El Niño phenomenon in the eastern Pacific.

Graduate student Terrie L. Klinger checks bars of tagged seaweed, two weeks after placing them at an underwater site off San Clemente Island.



A.C. Arneson

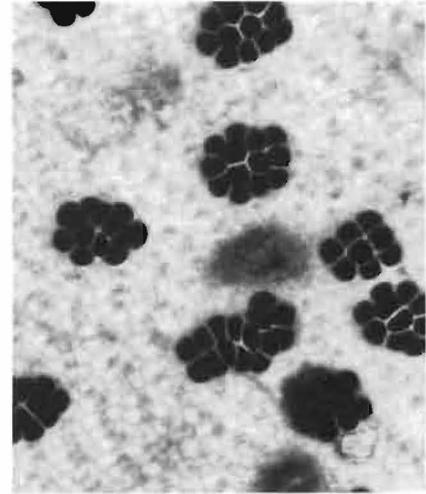
Ecology Group

Drs. Mia J. Tegner and Paul K. Dayton completed their studies of the Point Loma kelp forest's recovery after the massive disturbances associated with the 1982-1984 El Niño. Southern California kelp forests are diverse assemblages of plant and animal species organized around the competitive dominant *Macrocystis pyrifera*, commonly known as giant kelp. Despite the repeated disturbances that generally affected *Macrocystis* more severely than understory algae, *Macrocystis* rapidly reestablished its dominance. The initial storm in the winter of 1983 led to massive recruitment of many algal species. *Macrocystis* overgrew these species during the spring of 1983, but temperature-related nutrient stress during the warm El Niño summer and fall caused a complete canopy loss and poor survival. The *Macrocystis* canopy re-formed in

1984 and was lost; it re-formed again in 1985 and was lost, this time because of an amphipod outbreak. The 1986 *Macrocystis* population was healthy despite storm-induced mortality.

The population explosion of amphipods (an apparent secondary result of El Niño), normally found in the Point Loma kelp forest at much lower densities, caused the complete elimination of foliose macroalgae from areas of the forest, and grazing damage throughout the bed. The apparent reduction of amphipod predators, notably the kelp perch (*Brachyistius frenatus*) is believed to be the cause of the outbreak. This perch lives in close association with the *Macrocystis* canopy, and its populations decline sharply when kelp density decreases. The *Macrocystis* canopy was lost three times during a two-year period; kelp perch numbers apparently crashed; and amphipod densities increased.

Terrie Klinger removes the bracelets of seaweed from plastic pipes recovered from an underwater site. She will measure the seaweed's reproduction rate. At right is a magnified view of spores from one of the tagged seaweeds.



T. Klinger

The coastal kelp forests of southern California recovered more rapidly after this El Niño, despite its greater physical disturbances, than after the 1957-1959 event. This faster recovery was undoubtedly facilitated by the 15-year-old red sea urchin fishery and improvements in wastewater treatment since the early 1960s. The El Niño of 1957-1959 may have simply added the coup de grâce to an already destabilized community.

Graduate student Amatzia Genin studied how seamount topography and current patterns affect biological processes. Hydrographic surveys and current measurements show that seamounts alter the flows of impinging currents. Upwelling sometimes occurs over seamounts, but usually with no effect. The rich fisheries over shallow seamounts are apparently supported by advection of zooplankton from open water to the seamount. Large zooplankton such as krill are important food for rockfishes on seamounts.

Graduate students James P. Barry and Teresa L. Klinger are studying benthic ecology in the shallow waters of southern California. Barry's research centers on the processes that regulate or determine the structure of biotic communities on rocky intertidal reefs. Several interacting factors, including physical tolerance (or intolerance), competition, predation, grazing, substrate characteris-

After the 1957-1959 El Niño the decline and delayed recovery of many coastal kelp forests were associated with dense populations of sea urchins; therefore factors affecting these herbivores were carefully monitored after the recent El Niño. Despite the disturbance of the *Macrocystis* population, some algal drift—the major food for urchins—was al-

ways available and often abundant because of canopy deterioration. Urchin recruitment during 1983 and 1984 was the lowest observed in seven years of monitoring the Point Loma kelp forest. Given adequate food and little increase in population pressure, it was not surprising that destructive grazing episodes were negligible.

tics, and wave exposure restrict the abundance and distribution of plants and animals across the reef. Klinger is studying the three phases of seaweed life history (males, females, and sporophytes) in the brown algae family Dictyotales. She is investigating how maintaining three reproductive phases rather than just two affects the population. She is making field observations and experimenting with shallow subtidal populations along the mainland and the Channel Islands.

Marine Physics

Drs. Steven C. Constable and Charles S. Cox and graduate student Agusta H. Flosadottir make up one of only three groups in the world using controlled-source electromagnetism (E.M.) to study the ocean floor. Controlled-source E.M. and seismology are the only ways the earth's interior may be explored with a controlled source. The E.M. technique consists of forcing an electric current through the seafloor and measuring the resultant electric field some distance away. The electrical signal propagates

most readily through resistive rocks, decaying quickly in the conductive ocean, so signals measured away from the transmitter are sensitive only to seafloor conductivity.

Recent E.M. sounding activity has focused on oil exploration on the continental shelf. A group of four petroleum companies has funded new equipment and analytic techniques. Many geological structures (lava flows, carbonate reefs, and permafrost zones) that are difficult to explore with seismic reflection methods are relatively resistive and therefore amenable to electrical mapping.

The new equipment can be deployed from a small vessel. The 50-m transmitter antenna, towed on the seafloor directly behind the ship, injects 150 amperes into the seawater at frequencies of 32 to 1,024 Hz. The receiver is suspended close to the seafloor from a float, which is also towed behind the ship, but at the end of a long, floating rope. In this manner continuous surveys of seabed resistivity may be made at varying source-receiver spacings. The equip-

ment has been successfully tested off San Diego and should be available for an extended survey over an oil field later this year.

Collecting data is only a start; E.M. soundings may be interpreted using one-dimensional (1-D) models, but in the past this has usually meant assigning an arbitrary and simple layered structure to the earth. E.M. data can be inverted using a new technique to give a continuous 1-D structure, at the same time forcing the model to be maximally smooth. The real earth must then be rougher than the model, and any features in the model are likely to reflect earth structure. The sensitivity of the underwater E.M. method has been examined for various structures of interest in petroleum exploration. Further insight is obtained from Flosadottir's attempts to model the signal propagation within 1-D and 2-D structures using a modal analysis. This analysis clearly shows the tendency for the signal to propagate through resistive zones, and will be valuable in studying magma reservoirs at mid-ocean spreading centers.



Dr. Steven C. Constable compares the prototype of a release mechanism he designed with the original drawings.

PHYSIOLOGICAL RESEARCH LABORATORY



Emperor penguins preparing to go to sea near Cape Washington, Antarctica.

G. Kooyman

Scientists in the Physiological Research Laboratory concentrate on the behavioral, physiological, and biochemical adaptations of aquatic and terrestrial animals. In this report two of the several laboratory projects are highlighted.

Swimming and Diving: Air-Breathing Animals at Sea

Air-breathing animals have evolved remarkable adaptations to exploit the sea. Diving and breathholding are exquisite examples of how such animals survive in a hostile environ-

ment. The physiology and behavior of diving marine tetrapods continue to be central research topics in Dr. Gerald L. Kooyman's laboratory. This year he focused on emperor penguins' (*Aptenodytes fosteri*) behavior and energetics during hunting, and pinnipeds' cardiovascular response to exercise.

The emperor penguin project was a typical polar exploration requiring a four-day overland traverse to reach the study site. Dr. Kooyman, graduate student Donald A. Croll, and colleagues then set up camp on the sea ice, where they stayed for 75 days.

Dr. Kooyman and his researchers achieved a major technical breakthrough when they first deployed a prototype microprocessor-controlled recorder on a bird. With this recorder they obtained data on dive durations, patterning of dives, and other variables. The researchers measured dive depths greater than 300 m and found that the birds routinely hunted to depths of 200 m during dive bouts that lasted several hours. These observations define the birds' preferred feeding depths and their prey's distribution. The birds' diving prowess raises numerous questions on the physiology of diving—particularly the effects of pressure and gas exchange.

The penguin study is of special interest as a comparison to two of the smallest avian divers—the common murre and thick-billed murre. Diving behavior and energetics of these two species are Croll's research topics. He will use the large aquatic treadmill to determine the relationship between swim rate and metabolic rate in murre.

The field studies are closely related to laboratory investigations on cardiovascular response to exercise. Dr. Michael Castellini, a specialist in biochemical and vascular adaptations of seals, will help conduct the cardiovascular experiments.

Some experiments are being done on harbor seals in the Hydraulics Laboratory's flow channel. As the seals swim at different, controlled rates, or workloads, PRL scientists determine general exercise variables such as maximum oxygen consumption

rate and changes in blood chemistry and cardiac output. The researchers found that at the highest O₂ consumption rates seals continue to behave like divers with short breathholds and to use the suite of cardiovascular responses that occurs during breath-holding. Sea lions, however, shift to rhythmic breathing with no breath-holds at the highest O₂ consumption rates.

Dr. Paul J. Ponganis, applying his skills as an anesthesiologist, developed a technique to reliably obtain mixed venous blood. This technique makes it possible to measure several important physiological variables in an exercising marine mammal.

Breathing control in fish and cold-blooded, lung-breathing vertebrates depends on mechanisms that sense changes in the gas composition of the environment or in body fluids. The central nervous system reacts to these changes by altering the animal's ventilation rates and depths to regulate water flow across the gills, or airflow to the lungs. The result ensures adequate oxygen to support metabolism. Studies by Drs. Fred N. White and James W. Hicks showed that the evolutionary transition from water to air breathing was accompanied by a shift from ventilation control via oxygen sensitivity among fishes, to carbon dioxide sensitivity in lower-vertebrate lung breathers. Lung development was accompanied by a higher CO₂ body content because of the tidal flow of gas in lungs and the inability to completely renew the lung gas with ambient air. Fish characteristically exhibit blood par-

tial pressure of CO₂ similar to the water they breathe, around 2 mm Hg pressure. The blood and lung gas of reptiles is usually from 10 to 20 times this level.

Carbon dioxide is an important reactant in determining the acidity (pH) of the blood. Close control of pH is required to optimize many biochemical systems that are essential to normal metabolism. Fishes, being at low carbon dioxide levels that are in equilibrium with water, are unable to regulate pH by CO₂ control. Instead, the active transport of ions across their gills regulates the bicarbonate ion and thus pH. The large elevation of CO₂ accompanying lung breathing made it necessary to regulate breathing volumes to control CO₂ and thus achieve appropriate pH levels.

This shift from ventilation control by O₂ sensitivity in aquatic animals to CO₂ sensitivity in air breathers was not incompatible with assuring adequate O₂ availability as animals moved onto the land. This is because CO₂ production is directly linked to O₂ consumption. Thus, increased oxygen consumption by tissues results in increased CO₂ production. Sensory mechanisms that detect the carbon dioxide increase in blood force ventilation to higher levels, thus ensuring both the elimination of excess carbon dioxide and the availability of oxygen to support metabolic needs. Ventilation control in all lung-breathing animals was thought to involve sensory detection of oxygen levels. Drs. White and Hicks's views are in contrast to this traditional view.



*Dr. Gerald L. Kooyman and Dr. Paul J. Ponganis begin an autopsy on an Emperor penguin (*Aptenodytes fosteri*) found dead in Antarctica.*

VISIBILITY LABORATORY



Dr. Seibert Q. Duntley at work in the lab in 1957.

Visibility Laboratory

The Visibility Laboratory, for 35 years a part of the Scripps Institution of Oceanography, closed in July 1987. The laboratory was moved to San Diego from Massachusetts Institute of Technology by Dr. Seibert Q. Duntley at the invitation of Scripps in the summer of 1952. Laboratory scientists originally studied the visibility of objects in the atmosphere and in the ocean, and of submerged objects when viewed from above. This led to research in radiative transfer, environmental optics, image propagation, human vision, and photoelectric systems for detecting very-low-contrast objects.

Throughout the 35 years, laboratory scientists conducted major programs in atmospheric optics. They measured the optical properties of the troposphere; they also developed specialized measurement systems for aircraft, ground stations for monitoring the measurements, and optical propagation models based on the data obtained.

In the early 1960s, under the direction of James L. Harris, Sr., a research program was initiated in digital image processing. This led to a powerful, menu-driven software system that greatly facilitated his innovative research. That image processing

system has since been installed in various government and industrial laboratories.

In 1964 and 1965, laboratory researchers ran a series of major experiments on NASA's *Gemini 5* and *Gemini 7* spacecraft to assess how prolonged weightlessness and the cabin environment affect the vision of astronauts returning from extended missions.

From the late 1960s through the mid-1970s, airborne measurements of tropospheric optical properties were conducted worldwide under U.S. Air Force sponsorship, and in cooperation with research teams from five major European partners.

In optical oceanography, laboratory scientists were recognized nationally and internationally as leaders, both in the theoretical development of hydrologic optics and in the experimental aspects of instrumentation development and field measurement techniques. The scientists collected a major data base of optical properties from a variety of ocean areas. The data have been used to develop models of various properties.

In the early 1970s, researchers commenced optical sensing of the oceans. This work helped lay the foundation for the highly successful Coastal Zone Color Scanner flown by NASA on *Nimbus 7*. Laboratory scientists were participants on the NASA experiment team for that sensor, developing algorithms for atmospheric correction and determination of the optical diffuse attenuation coefficient of the water. They also conducted numerous cruises for surface validation studies, and worked with several agencies to apply the data gathered.

Through the years the Visibility Laboratory was funded by contracts and grants from federal agencies including various elements of the Navy

Roswell W. Austin calibrates an instrument to measure light-attenuation properties of ocean water.



and Air Force, NASA, NOAA, and NSF. Several active research programs have been transferred with the five principal investigators and some of the staff to other Scripps Institution units. These researchers will continue their work in satellite, aircraft, and ground-based remote sensing, and in hydrologic optics, photobiology, and descriptive optical oceanography.

The Visibility Laboratory's many contributions throughout the years were particularly facilitated by its three directors—Dr. Seibert Q. Duntley, James L. Harris, Sr., and Roswell W. Austin—and by John E. Tyler and the late Dr. Rudolph W. Preisendorfer.

CENTER FOR COASTAL STUDIES

Scientists at the Center for Coastal Studies (CCS) focus on the worldwide coastal environment, data acquisition systems and research instrumentation, and coastal protection and sediment management. CCS researchers investigate waves, currents, and tides in coastal, nearshore, and estuarine waters; sediment transport by waves, winds, and rivers; fluid-sediment interactions; and marine archaeology.

Dr. Douglas L. Inman, former CCS director, studied fluid-sediment interactions that cause sand transport along beaches and shelves, and form ripples, cusps, and bars. Dr. Inman and graduate student Hyunki Kim, in studies near the surf zone, showed that near-bed phenomena are controlled by shear waves and vortices that form in the accelerating fluid layer near the bed. The wavelength of the fluid motion determines the scale of the "roils" in carpet-flow sand transport, as well as the scale of the ripples that remain when motion stops. Intense motion causes the vortices to break up, or "burst," into plumes of sand and water, which scatter the sand into smooth beds.

Dr. Inman and graduate student Daniel C. Conley applied the findings from the oscillatory burst phenomena to an improved model for the longshore transport of sand. Coastal areas under study are the Nile Delta of Egypt, the coast of Israel, and the Outer Banks of North Carolina. Analysis shows that intermittency in coastal sand supply results in local areas of accretion and erosion that propagate along the coast with a

wavelike form. These "waves" have speeds of 2 to 4 kilometers per year. Dispersion causes the amplitudes of the "waves" to decrease with time.

In a collaborative study, CCS director Dr. Clinton D. Winant is investigating the upwelling processes that bring nutrient-rich cold water to the surface along the northern California coast. His data demonstrate that the amount of upwelling is directly related to wind strength over coastal waters. The very strong winds that characterize the northern California shelf during the spring-summer transition result from an interaction—similar to channel flow—between the marine layer and coastal topography. The physical characteristics of the marine layer are often such that the flow is supercritical, or the wind speed is greater than the speed at which pressure information propagates. As a consequence, wind speed increases as the coastline expands near Point Arena, and hydraulic jumps appear when the coast contracts the flow. These findings result from instrumental observations made by aircraft during the Coastal Ocean Dynamics Experiments.

Dr. Nancy A. Bray is studying thermohaline circulation in semi-enclosed seas, and the dynamics of straits that connect those seas to larger ocean basins. She is analyzing data from observations in the Gulf of California and the Strait of Gibraltar. In the Gulf of California, as in the Mediterranean Sea, evaporation exceeds precipitation, resulting in higher salinities in the gulf than in the Pacific. However, recent analyses suggest that, unlike the Mediterra-

nean, the gulf actually gains heat from the atmosphere on an annual average. As a result, the observed thermohaline structure and circulation in the gulf are quite different from most evaporative basins, which lose heat to the atmosphere. Whereas exchange between the Mediterranean and the Atlantic (also between the Red Sea and the Indian Ocean) occurs as surface inflow with colder, denser outflow, in the Gulf of California higher salinities are found near the surface, accompanied by surface-layer outflow and colder, fresher inflow at depth. This difference in thermohaline structure also affects water-mass formation, which in the gulf mainly results from mixing rather than from vertical convection.

Drs. Winant and Bray and graduate student Julio Candela are studying the flows through the Strait of Gibraltar as part of an international cooperative effort to develop an efficient method for long-term measurement. Such measurement will aid in understanding the exchange between the Atlantic and Mediterranean basins. Dr. Winant is focusing on pressure gradients as a means of explaining the balance of flows through the strait. Dr. Bray's concern is estimating heat and salt transport through the strait, and identifying the water masses circulating nearby.

Drs. Bray and Winant are also studying continental shelf circulation between San Francisco and the Oregon border. For this work, current meters (linked to transmitters sending the data to orbiting satellites) and bottom-pressure sensors have been

deployed. The data are relayed to Scripps's computers so that current flow can be plotted within six hours of the data recording.

Dr. Robert T. Guza and graduate students are observing and describing surface gravity waves and wave-induced currents in nearshore waters. Graduate student Eloi Melo-Filho is investigating the extraordinarily strong damping of waves propagating down the Mission Bay

entrance channel. The channel's rock walls appear to be very good energy absorbers. Graduate student William C. O'Reilly, using inverse theory and wave measurements from a few scattered locations, is estimating wave characteristics on the southern California coast. Offshore islands and shoals produce complex wave patterns at the coast, and wave heights can vary substantially over short distances. Graduate student Thomas H. C.

Herbers is developing a method to estimate the directional properties of waves in nearshore waters. His techniques will be used to measure wave reflection from natural beaches as well as from submerged breakwaters.

Robert L. Lowe and Dr. Guza are developing an acoustic Doppler system for directional wave measurements. (Existing systems are either very large, expensive, or inexact.) The prototype instrument measures the spatial derivative of velocity fluctuations, about doubling the resolution, and is compact enough for simple field use.

Dr. Scott A. Jenkins continues to focus on sediment management in harbors and estuaries in the Port of San Francisco. He also is working with an array of lifting bodies that prevents suspended sediments from settling.

Dr. Patricia M. Masters is reconstructing the physiographic environments of southern California's mid-Holocene shoreline by correlating data on 40 of San Diego County's underwater artifact sites with faunal analysis of onshore middens. The data indicate that an environmental transition occurred 4,000-5,000 years ago, when rocky, cobbly beaches turned into the present sandy littoral cells. Stable carbon and nitrogen isotope analyses on nine prehistoric human skeletons show a strong dietary dependence on marine foods.

Dr. Reinhard E. Flick (Department of Boating and Waterways) uses profile and sand budget measurements to study changes in local beaches. He studies California sea level changes to discern their relationship to meteorological forcing. He also is investigating temporal and spatial scales of surf and swash zone motions that are of higher frequency than incoming wave energy.



Dr. Nan Bray helps assemble a profiler package (CTD and water sampler) to measure conductivity, temperature, and depths through the water column.

CALIFORNIA SPACE INSTITUTE

The California Space Institute (Cal Space), headquartered at Scripps Institution of Oceanography, is a universitywide unit that supports and conducts space-related studies. Cal Space scientists, under the direction of Dr. James R. Arnold, promote new fields of research and explore future technologies and applications. To this end, Cal Space brings together university researchers and members of the industrial and private sectors. Each year the Cal Space mini-grant program provides seed money to UC researchers conducting space-related research ranging from theoretical astrophysics to satellite remote sensing. This year Cal Space invited scientists from across the country to present their research findings at a seminar that addressed diverse space-related topics, from materials processing to extraterrestrial life.

Cal Space researchers concentrate on space automation, robotics, and satellite remote sensing for oceanographic and meteorologic studies. Under the leadership of Associate Director Dr. Catherine H. Gautier, Cal Space's remote sensing branch hosted a workshop entitled "Climate Remote Sensing" in conjunction with France's Centre National d'Etudes Spatiales. The workshop was designed to familiarize young scientists with the techniques needed to extract climate data from satellite observations.

Cal Space scientists are participating in experiments to elucidate how earth's components (atmosphere, ocean, and land) interact on a global scale. Because earth-atmosphere interactions take place over large spatial scales, satellite remote sensing techniques are convenient means for studying global physical processes. As part of the Tropical Ocean Global Atmosphere Program, Drs. Gautier and Robert J. Frouin are using satellite observations to study the interannual variability of heat exchanges between the atmosphere and the Tropical Pacific Ocean. This region is crucial to variability studies of the earth's climate because here a large part of the heat accumulated by the ocean-atmosphere system is redistributed meridionally by ocean currents and transferred from the ocean to the atmosphere. The researchers are also studying how land surface and radiation processes interact, under the International Satellite Land Surface Climatology Program. This program seeks to improve satellite techniques for monitoring and specifying long-term land surface processes. One application is the monitoring of the Sahel desertification from satellite.

Drs. Mark R. Anderson and Gautier collaborated with Dr. Richard C. J. Somerville to study air-sea interactions and precipitation over the Indian Ocean during the monsoons. The researchers used a combination

of satellite observations, in situ observations, and simulations to examine how precipitation and large-scale heat fluxes over the Arabian Sea affect the onset and maintenance of the summer monsoon. Dr. Anderson is also continuing his research on polar ice regions through the use of passive microwave remote sensing.

Drs. John J. Bates and Gautier are collaborating with many other Scripps scientists to produce a nowcasting/forecasting capability of mesoscale eddy currents in the California Current system. By studying surface heat and momentum fluxes, Drs. Bates and Gautier will provide data on forcing functions needed for numerical ocean models to predict the evolution of the ocean's three-dimensional structure

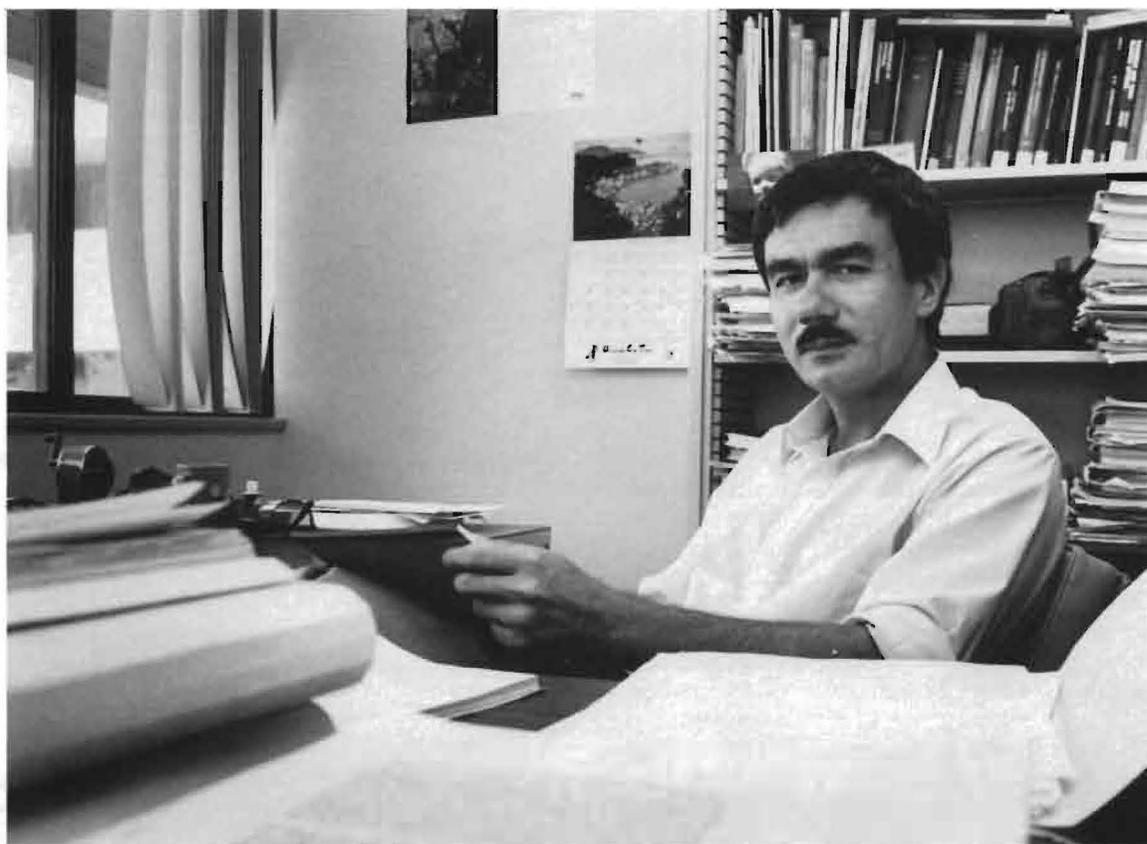
over short time scales (1-2 weeks). In order to help analyze the large satellite data sets, these researchers are also involved in developing new pattern-recognition techniques for satellite observations.

Drs. Gautier and Bates are also working on the Frontal Air-Sea Interaction EXperiment (FASINEX), designed to investigate the horizontal variability of the upper ocean and lower atmosphere. They are using satellite and ancillary data to analyze the variability of surface fluxes, the marine boundary layer, and cloud properties in association with thermal fronts.

With the ultimate goal of describing the initial stage of the carbon cycle in the ocean, Drs. Gautier and David W. Lingner are developing

methods to compute global marine primary productivity (phytoplankton concentration) by using satellite observations of ocean color, sea-surface temperature, and solar irradiance.

Satellite remote sensing techniques rely heavily upon computers and sophisticated programming algorithms to process the large, diverse satellite data sets. All the above research efforts are supported by extensive software development aimed at standardizing, simplifying, and unifying various software packages used to analyze satellite imagery. This software development is done in close collaboration and coordination with other research institutions and federal laboratories.



Dr. Robert J. Frouin works on ocean/atmosphere heat exchange 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 Institution, 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.

Dr. Duncan C. Agnew's crustal deformation research continued with an analysis of global earth-tide measurements. His study showed that both of the existing independent ocean-tide models predicted tidal gravity loads in accordance with the data and so could be used to model tidal displacement loading. Dr. Agnew, 10 graduate students, and colleagues from other institutions used the Global Positioning System satellites to measure the positions of numerous benchmarks in southern California. Future measurements will determine strain accumulation and refine the details of plate motion in this area.

Frank K. Wyatt III and Dr. Agnew direct work at the Cecil and Ida Green Piñon Flat Observatory, where instrument improvement and testing continues. Recently earth-tide data from closely spaced borehole tiltmeters were analyzed, indicating departures between these installations. Data from shallow tiltmeters have



Box for the underground seismographs at the Deep Springs, California, station.

confirmed the importance of near-surface soil motion, but also indicated a surprising degree of long-term stability.

Dr. Agnew continues to direct the 18-station Project IDA global seismic network. Seismologists use network data to study earth structure and earthquake mechanism.

Dr. Jonathan Berger and Jean-Francois Fels have embarked on a major upgrade of the Project IDA network, to equip it with three-component broadband seismometers and a new data logger developed by Fels. The first two stations have been deployed at the Piñon Flat Observatory and on Easter Island.

Drs. William E. Farrell and Berger continue their development of the digital feedback seismometer. The prototype model using a Streckeisen STS seismometer was successfully operated at Piñon Flat Observatory.

An improved version now under development will provide sensors for the upgraded Project IDA network.

Drs. Berger and Holly Eissler began high-frequency seismic investigations in cooperation with the Soviet Academy of Sciences. Funded by the Natural Resources Defense Council, three state-of-the-art seismographic stations were established near the principal USSR nuclear weapons test site in eastern Kazakhstan, and three near the U.S. test site in Nevada. Graduate students from IGPP and the University of Nevada, Reno, have spent the last year in Kazakhstan operating the network and working with Soviet colleagues to analyze data. U.S. network data will be telemetered by satellite to La Jolla for event detection and recording. Data collected by this project are relevant to several seismological problems associated with the monitoring and verification of present and future test-ban treaties.

Drs. James N. Brune and Berger, and graduate students Frank L. Vernon and Jennifer S. Scott have been operating the ANZA seismographic array in collaboration with U.S. Geological Survey scientists. Drs. John G. Anderson and T. Guy Masters, graduate student Susan E. Hough, and others are studying the data from this array.

Drs. Brune and Anderson continued studies of seismic hazard, earthquake strong motion, earthquake mechanism, and earth structure in collaboration with Mexican colleagues. They are clarifying and estimating the probabilities of large ground accelerations that might damage major structures.

The earthquake that struck Mexico on September 19, 1985, occurred in a likely location for a large earthquake—a location that had been included in a network of instruments to record strong ground motion. Consequently, unprecedented high-quality records of strong shaking

were obtained. Unique to these records is the observation of the ground above the fault during the earthquake. Another earthquake (magnitude of only 5.4) on February 7, 1987, at Cerro Prieto volcano in the Mexicali Valley produced some of the strongest ground motions ever recorded. Dr. Anderson and an Iranian colleague also studied the strong motion records of the 1978 earthquake in Tabas, Iran.

Drs. Brune and Anderson continue their study of high-frequency (30 Hz) seismic wave excitation of earthquakes for use in distinguishing nuclear explosions from earthquakes.

Dr. Anderson, Hough, and Dr. Michael S. Reichle (California Division of Mines and Geology) studied the attenuation of seismic waves at high frequencies at Anza and Parkfield, California.

Drs. Brune and Ralph H. Lovberg continued to study site effect and seismic engineering problems of earthquake hazard, using 3-D, foam rubber topographic models. Physical modeling of these problems joined with computer modeling results in a cross-check of both techniques.

Dr. Allen H. Olson developed an iterative model for solving very large, and potentially ill-conditioned, least-



Soviet and Scripps scientists install a borehole seismometer in eastern Kazakhstan.

H. Eissler

Frank L. Vernon III sets up a seismometer at Deep Springs, California, for a project in cooperation with the Soviet Academy of Sciences.

squares problems. The algorithm encompasses a general class of modern iterative methods common in seismic tomography. Using the mathematical properties of Chebyshev polynomials, Dr. Olson showed that the number of iterations needed to obtain a given level accuracy could be reduced from n to \sqrt{n} .

The Chebyshev method was used by Drs. Olson and Anderson as part of a linear inversion study in which the space-time dependence of slip on an extended fault was reconstructed with ground motion data from a known slip model. The researchers used a CRAY X-MP/48 supercomputer to determine 1,300,000 slip parameters from approximately 3,000 data values. The study revealed a fundamental trade-off in this inverse problem between the spectral amplitude of slip at a point on the fault and the local phase velocity of slip propagation.

Drs. John A. Orcutt and Alistair J. Harding, and several graduate students used seismic methods to solve a number of geological and geophysical problems. Dr. Orcutt and graduate student Mark S. Burnett used the San Diego Supercomputer to study seismic waves that propagate around large bodies of molten magma underlying the mid-ocean ridges. Dr.

Orcutt and graduate student David W. Cares are developing geometrical optical and higher-order methods to study seismic wave propagation in complex and realistic elastic media, with an eye to using seismic information to construct images of the internal structure of mid-ocean ridges.

Drs. Harding and Orcutt and graduate student Mary E. Kappus analyzed an extensive multichannel data set collected on the East Pacific Rise and mapped the evolution of the young oceanic lithosphere from a partially molten zone at the rise axis to the effectively mature crust less than 250,000 years old. They have found that the rock underlying the linear volcanoes of the world's mid-ocean ridges is only partially molten and that lithosphere accretion occurs through the regular injection of molten sills within the young lithosphere. Dr. Orcutt and graduate student Michael A. Hedlin constructed complete models of seismic wave propagation through realistic media and have designed algorithms to study how seismic instrumentation itself affects the wavefield recorded.

Graduate student Kenneth M. Toy and Dr. Orcutt, with Drs. J. Freeman Gilbert and Allen H. Olson, reconstructed multidimensional models of earth's interior from global network data sets. The researchers computed new standard models for earth structure that will lead to more accurate locations for earthquakes, and they demonstrated that earth's inner core is likely to be anisotropic. Graduate student Isaac I. Kim and Dr. Orcutt used seafloor morphology maps to correct seismic images of the deeper interior of the earth. Graduate student Donald G. Albert and Dr. Orcutt have developed wave-propagation techniques that correctly couple atmospheric acoustic waves and elastic

waves in the solid earth. Graduate student Dalia Lahav and Dr. Orcutt adapted low-frequency acoustic sensors developed by Drs. Charles S. Cox and Spahr C. Webb to the Scripps ocean-bottom seismographs for studying the upper mantle underlying the oceans.

Drs. Hugh Bradner and Reichle continued the spectral analysis of low-frequency seismic noise, out to 0.02 Hz, using records collected by Lamont-Doherty Geological Observatory scientists at a site 200 km west-northwest of San Francisco.

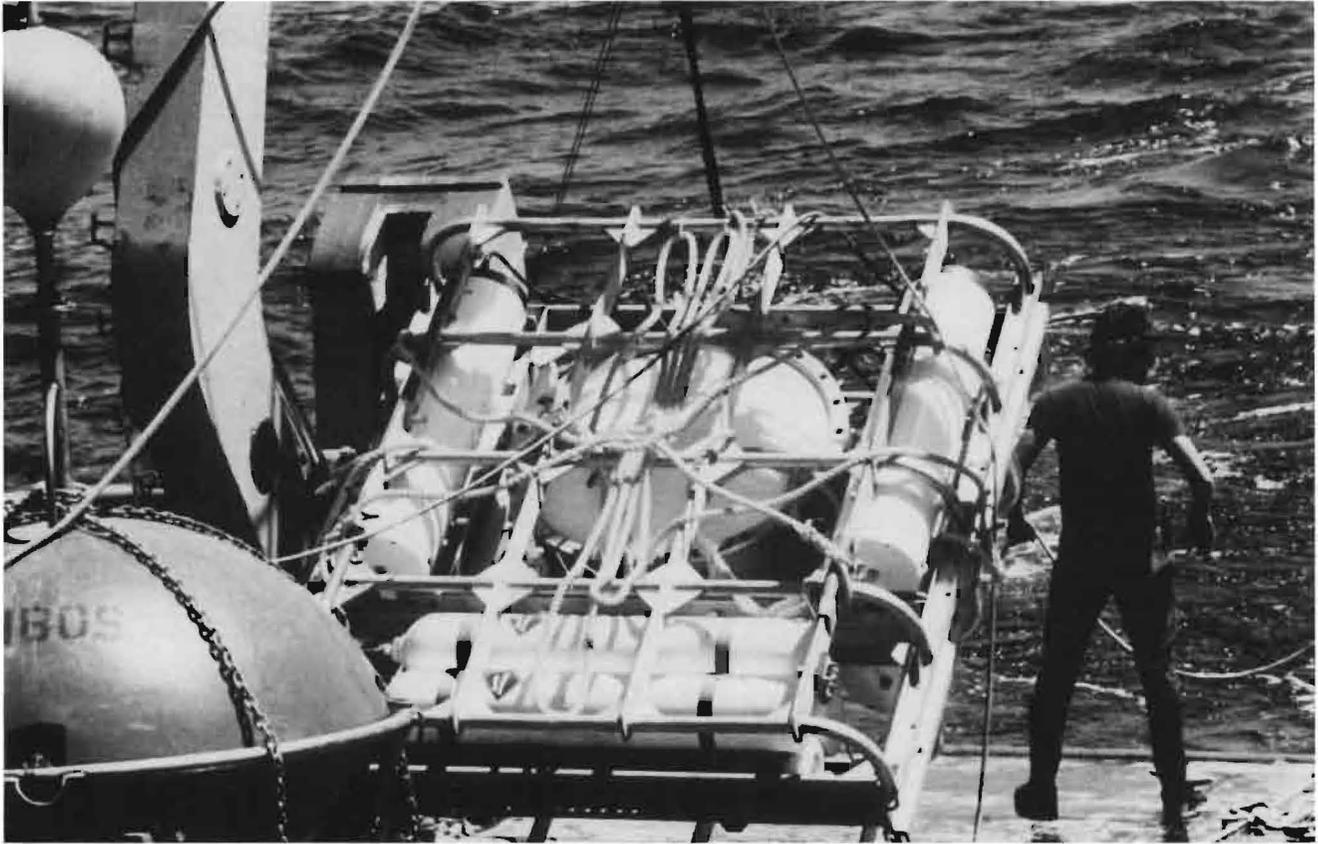
Dr. Mark A. Zumberge, graduate students Glenn S. Sasagawa and J. Mark Stevenson, and others are helping to determine the Newtonian gravitational constant. The group will calculate G by measuring the variation of earth's gravity in a borehole through the Greenland Ice Sheet.

Dr. George F. Backus refined a scheme for modelling electric currents at satellite altitudes, to facilitate the reduction of satellite magnetic data. He also developed a simplified approach to vector and tensor spherical harmonics for use in reducing satellite gradiometer measurements of the geomagnetic and gravity fields. He developed remedies for the usually unrecognized failure of uniqueness in stochastic inversion and Bayesian inference.

Dr. Robert L. Parker, working with his graduate student Catherine G. Constable and Dr. Steven C. Constable, has perfected a new method of inverting the nonlinear problems of electrical sounding. The essential principle is to minimize a functional of the model that penalizes a bulk measure of slope or curvature. This suppresses unnecessary oscillations and jumps, which can easily arise and which might be given undue prominence in geophysical interpretation. Dr. Parker and graduate student Philip B. Stark have applied the same principle to a classical seismology problem—the inversion of travel-time data base upon τ - p and X - p observations. In this case an un-

A new low-frequency sound transmitter for ocean acoustic tomography is readied for sea testing.

IGPP



conventional measure of model wiggliness leads to a direct solution in terms of quadratic programming. Previous inversion schemes using linear or quadratic programs have yielded velocity profiles with unrealistically steep gradients that are quite unsuitable for geological interpretation.

Drs. Peter F. Worcester, Walter H. Munk, Robert A. Knox, Bruce M. Howe, and Bruce D. Cornuelle continued their research in ocean acoustic tomography. Newly designed acoustic sources and receivers were tested and used successfully at sea; this latest generation of equipment allows tomographic sound transmissions over distances of 1,000 km. Tomographic moorings using such long ranges to measure large-scale average conditions in a triangular region of the North Pacific have been deployed and will be recovered for data analysis next year. A long study

and test of the advantages and limitations of carrying out tomographic measurements from ships, as opposed to fixed moorings, has begun. First steps include considerable computer analysis of the mapping accuracy and resolution to be expected with different ship-track strategies and with reasonable assumptions about instrument performance and measurement errors.

Dr. John W. Miles, with graduate students Janet M. Becker and Diane M. Henderson, continued his studies of nonlinear waves and chaotic motion in dynamical systems. Bernard D. Zetler is concentrating on contributions to the history of geophysics.

INSTITUTE OF MARINE RESOURCES

The universitywide Institute of Marine Resources (IMR), headquartered at Scripps and directed by Dr. Fred N. Spiess, administers food chain and ocean engineering programs, and the California Sea Grant College Program. Two of IMR's activities, ocean engineering and polar research, are highlighted this year.

Ocean Engineering

The Ocean Engineering Research Group (OERG), directed by Dr. Richard J. Seymour, continues a program in applied oceanography with major emphasis on Pacific Coast wave climatology. New instruments, including three directional arrays and an anemometer, were installed in Monterey Bay to verify refraction models in cooperation with the Navy Postgraduate School. A new wave gage and a downward-looking Doppler sonar current meter were also installed on a tower 11 km offshore of Point Conception to measure the California Current on the shelf.

In collaboration with the National Oceanic and Atmospheric Administration's scientists on the Pacific Tsunami Observation Program, OERG researchers developed a tsunami watch within Wave Network facilities. The watch provides continuous data for studying coastal amplification of tsunamis. Researchers are analyzing data of longshore momentum flux estimators, and using the group's Wave Network data from the Barbers Point Harbor on Oahu to study infragravity waves that generate harmful surges or seiches within harbors. The scientists designed and installed a computer-controlled, automatic-pressure-sensor calibration

facility that maintains instruments at low temperatures for long periods and verifies long-term drift characteristics. High-resolution quartz crystal pressure sensors were implemented in the directional arrays that have enhanced reliability in sensors and in mean water-depth measurement. The fabrication and installation of a second-generation data collection receiver improved the reliability of data retrieval over telephone lines from remote field stations.

Drs. Dimitri Alexandrou and Seymour collaborated to develop a hybrid sonar for bathymetric mapping in water less than 20 m deep. Dr. Alexandrou is evaluating the use of Sea Beam data for remote ocean-bottom roughness classification and for scattering-layer studies. He is working with Dr. Kenneth L. Smith's group on the development, testing, and signal processing of an active sonar system to estimate vertical biomass flux in the deep ocean.

Dr. Toyooki Nogami is developing a numerical nonlinear model of pile foundations subjected to dynamic transient loading from earthquakes. He is also developing an analytical model for the seismic response of a large number of piles in a group. He has initiated cooperative structural testing programs in the Powell Structures Laboratory at UCSD and, with the Japanese, is investigating soil/structures interactions under seismic loading.

Graduate student David B. King continues a large-scale study of sand movement in response to mixed oscillatory and mean flows. Dr. Seymour is modeling time-and-space-varying turbidity flows associ-

ated with strong swash motions on beach faces during storms. A second-generation in-flight digital recording system for the AXBT (airdroppable expendable bathythermograph) has been developed and successfully demonstrated in a Central Pacific experiment.

Dr. Seymour's group is collaborating with Dr. Victor C. Anderson and University of Washington scientists on an experiment off San Clemente Island to simulate the environmental impact of rapid sedimentation caused by deep ocean mining.

Polar Research

Polar Research Program scientists, headed by Dr. Osmund Holm-Hansen, study the oceans in both the Arctic and Antarctic. Major emphasis is placed on the microbial food web and on physiological/biochemical adaptations related to the severe polar conditions. Studies focus on biological problems, but are usually multidisciplinary. Thus distribution and metabolic activity of planktonic organisms can be interpreted in relation to physical, chemical, and optical factors. These studies constitute single components of large national or international programs.

Although the two polar regions are somewhat similar, many of their oceanographic conditions and their biota differ widely. Research in both regions emphasizes the importance of physical mixing processes on the distribution and metabolic activity of planktonic organisms.

The Research on Antarctic Coastal Ecosystem Rates (RACER) program is managed by the Polar Research Program and includes 25 investigators from eight countries. Field studies

Dr. Osmund Holm-Hansen plots data gathered in the Antarctic.



extended from austral spring to autumn on board the Norwegian R/V *Polar Duke* (leased to the National Science Foundation), operating out of Palmer Station on Anvers Island, west of the Antarctic Peninsula. Key Scripps personnel included Drs. Mark E. Huntley, Edward Brinton, Pearn P. Niiler, and B. Gregory Mitchell. The basic question addressed by the RACER program is: Why is the Antarctic continental shelf area so productive compared to areas of the Southern Ocean? This is particularly important for the shelf area of the Antarctic Peninsula, which is thought to be a nursery ground for krill, a key organism in the food chain.

The RACER studies focus on a relatively small area (100 x 250 km) that includes the southwest Bransfield Strait and a portion of the deep Drake Passage. The distribution and functioning of planktonic organisms are documented both temporally and spatially, yielding better understanding of the interaction of physical, chemical, and optical factors on the biota. Between December and April, R/V *Polar Duke* made eight complete surveys of the RACER area, covering a grid of 69 hydrographic stations. The program included physical, meteorological, optical,

and chemical measurements to complement intensive studies on bacterioplankton, phytoplankton, zooplankton, and krill.

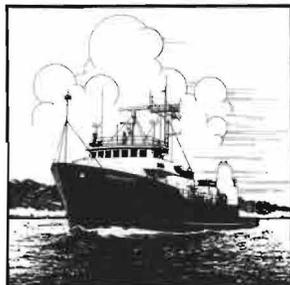
One of the key hypotheses of the RACER program is that upper ocean physical dynamics stabilize relatively shallow upper mixed layers, increasing the mean photoregime experienced by phytoplankton cells. To test this hypothesis, the scientists employed a newly designed profiling unit that operates on standard single-conductor cable and records continuous data from 18 channels between 0 and 200 m, in addition to recording incident solar radiation. Water samples were obtained from Niskin bottles mounted on the profiling unit, and were used to measure spectral absorption and fluorescence of the particulate material, in addition to photosynthetic rates. Data from more than 300 profiles obtained with this unit show that, in general, phytoplankton biomass was uniformly distributed throughout the upper mixed layer, below which it decreased rapidly. Phytoplankton biomass ranged from 0.2 to over 20 μg chlorophyll-*a* per liter, while primary productivity ranged from 80 to 4,000 mg carbon per m^2 per day. High biomass and primary produc-

tion were always associated with relatively shallow upper mixed layers. The in situ optical data, combined with the optical and photosynthetic characteristics of the phytoplankton, are being used to assess the photoadaptational status of the phytoplankton.

Late spring-early summer Arctic studies on board F/F *G. O. Sars*, from the University of Bergen, Norway, were a continuation of work in the Barents Sea, which was started in 1984 as part of a large ecosystem analysis organized and managed by Norwegian scientists. This six-year project (1984-1989), consisting of both descriptive and basic process-oriented studies, is designed to clarify the Barents Sea ecosystem, for proper management of its living resources.

Much of the Barents Sea is covered by seasonal ice, which affects the physical dynamics and biology of the upper water column. Studies included the seasonal transition from well-mixed and nutrient-rich waters to a highly stratified and nutrient-depleted upper water column. At stations where the latter situation prevailed, phytoplankton biomass was very low in the upper mixed layer, but much higher (up to 10 μg chlorophyll-*a* per liter) immediately below the pycnocline. Using an 18-channel profiling unit, scientists made optical measurements in the upper 200 m of the water column. Photoadaptational responses and specific growth rates of phytoplankton as related to in situ light conditions were studied under the direction of Dr. Maria Vernet. Because the upper water column is depleted of essential plant nutrients in summer, phytoplankton biomass and metabolic activity must be interpreted in terms of both light flux and possible effects of nutrient deficiency. This contrasts sharply with Antarctic waters, where nutrients are generally in high concentration, and variations in phytoplankton chemical composition and photosynthetic rates can be related solely to the photoregime to which the cells are exposed.

Seagoing Operations



R/V *New Horizon*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
06/29-07/20/86	Bempex II	Off Oahu	Biological studies	Honolulu	J. Childress (UCSB)	L. Davis
07/24-08/18/86	Bempex III	38°–48°N, 145°–155°W	Seafloor studies	Honolulu	A. Chave/ J. Filloux	P. Munsch
08/21-09/14/86	Bempex IV	40°N, 162°W	Acoustic tomography/ deployment	San Diego	P. Worcester	P. Munsch
09/18-10/03/86	CalCOFI 8609	Southern California Bight	Physical, chemical and biological studies	San Diego	E. Venrick	T. Desjardins
10/08-10/12/86		San Clemente Basin	Marine biology	San Diego	J. Childress (UCSB)	T. Desjardins
10/14-10/25/86		San Pedro, Santa Monica, Santa Barbara basins	Basin studies	San Diego	B. Hickey (UW)/ L. Small (OS)	P. Munsch
10/29-11/07/86		Santa Barbara Channel	Ecological physiology	San Diego	C. Fisher (UCSB)	P. Munsch
11/11-11/26/86	CalCOFI 8611	Southern California Bight	Physical, chemical, biological and meteorological studies	San Diego	A. Mantyla	P. Munsch
12/12/86			NSF inspection			P. Munsch
02/24/87			Sea Trials			P. Munsch
03/02-03/16/87		San Pedro Channel	Biological studies	San Pedro	R. Pieper (USC)	P. Munsch
03/17-03/25/87		Santa Monica, San Nicolas basins, Patton Escarpment	Geological studies	San Diego	W. Berelson/ D. Hammond (USC)	P. Munsch
03/31-04/15/87	CaBS 5	San Pedro, Santa Monica, Santa Barbara basins	Current studies	San Diego	A. Carlucci/ B. Hickey (UW)	P. Munsch
04/28-05/23/87		North of San Francisco	Physical, chemical and biological studies	San Diego	T. Hayward	P. Munsch
05/25/87			Student cruise	San Diego	M. Mullin	P. Munsch
06/08-07/09/87		40°N, 150°W	Recovery	Honolulu	J. Filloux	L. Davis

TOTAL DISTANCE TRAVELED: 23,775 nautical miles OPERATING DAYS: 238

R/V Robert Gordon Sproul

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
07/08-07/11/86		San Clemente Basin	Carbonate studies	San Diego	C. Reimers	T. Beattie
07/16-08/16/86		Sea of Cortez	Shark studies	San Diego	P. Klimley	T. Beattie
08/20-08/28/86	San Nicolas/ Catalina basins		Biological studies	San Diego	D. Hammond/ W. Berelson (USC)	T. Beattie
09/04-09/10/86		Southern California Bight	Food chain studies	San Diego	R. Eppley	T. Beattie
09/11/86		Southern California coast	Equipment testing	San Diego	M. Ohman	T. Beattie
09/15-09/19/86		Santa Catalina Basin	Equipment testing	San Diego	K. Smith	T. Beattie
09/23-09/26/86		San Nicolas Basin	Equipment testing	San Diego	M. Gowing (UCSC)	T. Beattie
10/02-10/03/86		San Diego Trough	Equipment testing	San Diego	K. Smith	T. Beattie
10/05-10/08/86		Santa Barbara Basin	Tracer studies	San Diego	C. Reimers	T. Beattie
10/20-11/08/86		Half Moon Bay area	Equipment testing	San Diego	J. Turcotte (Navy)	T. Beattie
11/12-11/14/86		Southern California coast	Biochemical studies	San Diego	E. Brinton	T. Beattie
11/17/86		San Diego Harbor	Equipment testing	San Diego	O. Holm-Hansen	T. Beattie
12/10-12/11/86		Southern California coast	Biological studies	San Diego	A. Yayanos	T. Beattie
12/17-12/22/86		119°–123°W, 26°–29°N	Current studies	San Diego	P. Niiler	T. Beattie
01/06-01/13/87		Southern California Bight	Plankton studies	San Diego	R. Eppley	T. Beattie
01/20-01/22/87		Southern California coast	Equipment testing	San Diego	R. Davis/ L. Reiger	T. Beattie
02/03-02/06/87		Santa Barbara Channel	Box cores	San Diego	W. Berger	T. Beattie
02/17/87			Assist with <i>Thomas Washington</i> gravimeter test	San Diego	—	T. Beattie
02/23-02/25/87		Southern California Bight	Equipment testing	San Diego	P. Niiler	T. Beattie
02/28/87		Southern California coast	Student cruise	San Diego	R. Rosenblatt	T. Beattie
03/06-03/07/87		Southern California Bight	Equipment testing	San Diego	R. Davis/ L. Reiger	T. Beattie
03/10-03/12/87		Southern California coast	Benthic biology	San Diego	A. Yayanos	T. Beattie
03/23-03/27/87		Santa Monica Bay/Santa Barbara Channel	Benthic biology	San Diego	R. Vetter	T. Beattie
04/06-04/11/87		San Clemente/Catalina	Benthic biology	San Diego	T. Klinger	T. Beattie
04/13-04/15/87		Southern California coast	Optical studies	San Diego	K. Voss	T. Beattie
04/17-04/30/87		Baja California	Box coring	San Diego	R. Jahnke	T. Beattie
05/02/87		Southern California coast	Student cruise	San Diego	G. Kooyman	T. Beattie
05/03-05/04/87		Transit		Ventura	—	T. Beattie
05/05-06/02/87		Point Conception	Ecology studies	San Diego	Butman/Campbell/ Hardin (Battelle)	T. Beattie
06/06-06/09/87		33°N, 121°W	OBS recovery	San Diego	L. Dorman	T. Beattie
06/09-06/14/87		Southern California coast	Marine biology	San Diego	C. Cary	T. Beattie
06/14-06/16/87		Santa Barbara Basin	Biological studies	San Diego	A. Schimmelmann	T. Beattie
06/22-06/28/87		Santa Monica Basin	Basin studies	San Diego	N. Kachel (UW)	T. Beattie

TOTAL DISTANCE TRAVELED: 15,909 nautical miles OPERATING DAYS: 185

R/V Melville

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
07/08-07/26/86		Off Hawaii	Deep Tow	San Diego	F. Spiess	C. Johnson
10/16-11/08/86		30°–27°N, 122°–45°W	Ocean bottom seismology	San Diego	L. Dorman	C. Johnson
11/11-12/15/86		Southern California	Benthic biology	San Diego	K. Smith	C. Johnson
03/03/87			Sea Trials			C. Johnson
03/20/87			Sea Trials			C. Johnson
03/31/87			Sea Trials			C. Johnson
04/10-04/25/87	Circus	Southern California	Thruster test, ocean bottom seismology	San Diego	F. Spiess/L. Dorman/ J. Hildebrand	C. Johnson
05/02-05/26/87		40°N, 162°W	Acoustic tomography	Honolulu	P. Worcester	C. Johnson
05/27-05/30/87		Near Oahu	Dredging	Honolulu	J. Natland	C. Johnson
06/03-07/11/87		Central North Pacific	Benthic biology	San Diego	K. Smith	C. Johnson

TOTAL DISTANCE TRAVELED: 11,615 nautical miles OPERATING DAYS: 174

R/V Thomas Washington

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
07/04-07/20/86	Papa-Tua Xc	Yellow Sea	Physical oceanography	Sasebo	R. Limeburner (WHOI)	T. Desjardins
07/23-08/20/86	Papa-Tua XI	Adak Island	Sea Beam and fish trapping	San Diego	P. Lonsdale/ K. Smith	T. Desjardins
08/21/86-02/13/87		OUT OF SERVICE				
01/23-01/24/87		Sea trials			E. Winterer	T. Desjardins
02/17-03/25/87	Crossgrain I	South Pacific	Sea Beam, dredging	Papeete	E. Winterer	T. Desjardins
03/29-04/25/87	Crossgrain II	Marquesas Island Swell	Geology with Sea Beam	Papeete	M. McNutt (MIT)/ J. Natland	T. Desjardins
04/29-06/03/87	Crossgrain III	Line Islands	Manganese nodule studies	Hilo	D. Cronan (IC)	A. Arsenaault
06/03-06/07/87	Crossgrain IV	East Rift Zone	Geophysical, airgun, magnetic profiling	Honolulu	C. de Moustier/ P. Lonsdale	A. Arsenaault
06/10-06/13/87	Crossgrain V	Hawaiian waters	Sea Beam	Honolulu	D. Hussong (UH)	T. Desjardins
06/17-06/26/87	Crossgrain VI	North Pacific	Landers, deployment	Hilo	D. Hammond/ W. Berelson (USC)	T. Desjardins

TOTAL DISTANCE TRAVELED: 33,671 nautical miles OPERATING DAYS: 180

R/P FLIP

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	O-in-C *
08/18-08/28/86		San Diego Trough	Equipment tests	San Diego	F. V. Pavlicek	D. Efird
09/26-10/30/86	PATCHEX	32°-50°N	Physical oceanography	San Diego	R. Pinkel	D. Efird
01/27-01/29/87	PATCHEX	San Diego Trough	Array tests	San Diego	F. Fisher	D. Efird
03/14-04/03/87	BAMBINO I	32°-50°N, 125°W	Acoustic propagation	San Diego	F. Fisher	D. Efird
06/15-06/24/87	VIA test	32°-37°N, 120°-133°W	Array tests	San Diego	J. Hildebrand	D. Efird

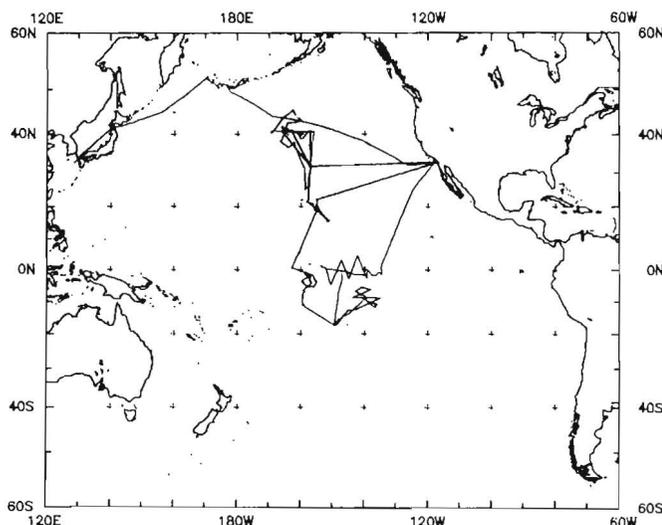
TOTAL DISTANCE TRAVELED: 2,317 nautical miles OPERATING DAYS: 77 * OFFICER-IN-CHARGE OF FLOATING PLATFORM

R/P ORB

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	O-in-C *
12/04-12/10/86	SSNI Test	San Diego Trough	Surface acoustic noise	San Diego	G. Updegraff	T. Hoopes
01/26-01/30/87	DARNOORR I	San Diego Trough	Acoustic array tests	San Diego	J. Hildebrand	T. Hoopes
03/21-03/26/87	SSNI Test	San Diego Trough	SSNI/RUM array tests	San Diego	G. Updegraff	T. Hoopes

TOTAL DISTANCE TRAVELED: 107 nautical miles OPERATING DAYS: 15 * OFFICER-IN-CHARGE OF FLOATING PLATFORM

Track chart of major cruises, July 1986 through June 1987.



RESEARCH VESSELS OF SCRIPPS INSTITUTION OF OCEANOGRAPHY

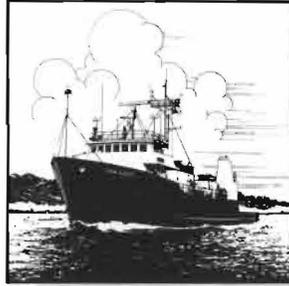
	<i>MELVILLE</i>	<i>NEW HORIZON</i>	<i>ROBERT GORDON SPOUL</i>	<i>THOMAS WASHINGTON</i>	FLIP	ORB
TYPE:	Oceanographic research	Oceanographic research	Offshore supply	Oceanographic research	Floating Instrument Platform	Oceanographic Research Buoy
YEAR BUILT:	1969	1978	1981	1965	1962	1968
YEAR ACQUIRED BY 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**	13-19**	12-18**	22	10	10

1986-87 Total nautical miles steamed: 87394 1986-87 Total operating days: 869 *Depends on towing vessel **With berthing vans



R/V New Horizon departs San Diego.

Graduate Department



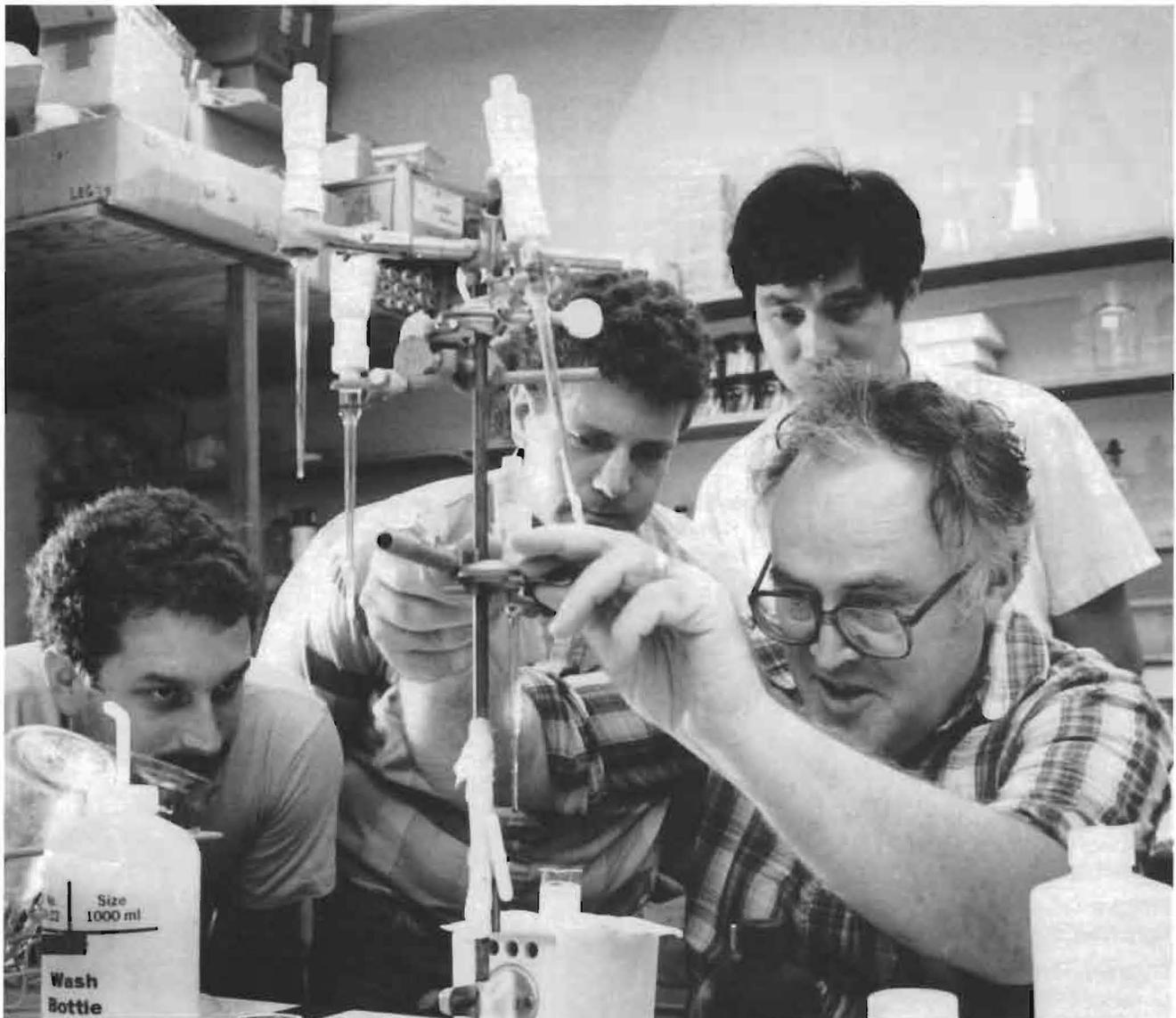
The Graduate Department of the Scripps Institution of Oceanography offers instruction leading to Ph.D. degrees in oceanography, marine biology, and earth sciences. Because of the interdisciplinary nature of the ocean sciences, the department provides a choice of seven curricular programs through which 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 Engineering and Computer Sciences, 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.

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, micro-

Dr. Joris M. Gieskes demonstrates a titration technique to two students and a colleague. left to right, Andrew J. Magenheim, Timothy J. Shau, and Yong-Chen Wang.



paleontology 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.

Marine Chemistry. Marine chemists are concerned with chemical and physical properties of seawater as well as the chemical processes operating within the oceans, in the marine atmosphere, and on the seafloor. Research programs are

based on the interactions of seawater components with the atmosphere, with sedimentary solid phases, and with marine plants and animals.

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 1986, 32 new students were admitted to graduate study. Of these, 4 were in marine biology, 5 in geological sciences, 6 in marine chemistry, 5 in geophysics, 2 in physical oceanography, 5 in applied ocean sciences, and 5 in biological oceanography. Enrollment at the beginning of the academic year was 182. UC San Diego awarded 7 Master of Science degrees and 25 Doctor of Philosophy degrees to the students listed below.

Doctor of Philosophy Degrees Awarded, with Titles of Dissertations

Earth Sciences

Timothy J. Bralower, "Part A: An Integrated Mesozoic Biochronology and Magnetostratigraphy—Part B: Studies of Cretaceous Black Shales."

Catherine G. Constable, "Some Statistical Aspects of the Geomagnetic Field."

Michael H. Ritzwoller, "Observational Constraints on the Large Scale Aspherical Structure of the Deep Earth."

Allan W. Sauter, "Studies of the Upper Oceanic Floor Using Ocean Bottom Seismometers."

Philip B. Stark, "Travel Time Inversion: Inference and Regularization."

Elizabeth Wright, "Petrology and Geochemistry of Shield-Building and Post-Erosional Lava Series of Samoa: Implications for Mantle Heterogeneity and Magma Genesis."

Marine Biology

Daniel C. Abel, "Pericardial-Cardiac Interactions and the Role of the Pericardioperitoneal Canal in Elasmobranch Fishes."

John L. Butler, "Comparison of the Early Life History Parameters of Pacific Sardine and Northern Anchovy and Implications for Species Interactions."

Edward F. DeLong, "Adaptations of Deep-Sea Bacteria to the Abyssal Environment."

Susan J. Roberts, "The Association of the Glycolytic Enzyme Phosphofructokinase with Filamentous Actin."

James S. Trimmer, "Sea Urchin Sperm Surface Antigens Mediating the Acrosome Reaction."

Robert S. Waples, Jr., "A Multispecies Approach to the Analysis of Gene Flow in Marine Shore Fishes."

Oceanography

Vittorio Barale, "Heterogeneity of the Ocean Color Field: A Descriptive Analysis for Oceanic, Near-Coastal and Enclosed Basin Conditions."

Pierre J. Flament, "Subduction and Finestructure Associated with Upwelling Filaments."

Amatzia Genin, "Effects of Seamount Topography and Currents on Biological Processes."

Gary D. Gilbert, "The Effect of the Vertical Displacement of Subsurface Water on Upwelled Light."

Nancy W. Hinman, "Organic and Inorganic Chemical Controls on the Rates of Silica Diagenesis: A Comparison of a Natural System with Experimental Results."

Eric S. Johnson, "Studies of Doppler Acoustic Velocities Measured During the NORPAX Hawaii-to-Tahiti Shuttle."

Victor H. Marin, "Distribution and Life Cycle of Three Antarctic Copepods (*Calanoides acutus*, *Calanus propinquus*, and *Rhincalanus gigas*)."

Christopher V. Metzler, "Constraints on the Deposition and Diagenesis of Jurassic Carbonates, Italy and Switzerland."

Lauren S. Mullineaux, "The Epifaunal Communities of Manganese Nodules."

Jeffrey M. Napp, "The Vertical Distribution and *in situ* Feeding of Marine Particle-Grazers in Relation to Their Food, the Microplankton."

James R. Nelson, "Phytoplankton Carotenoids as Organic Tracers in Marine Particulate Organic Matter."

Albert J. Plueddemann, "Observations of the Upper Ocean Using a Multi-Beam Doppler Sonar."

Jae S. Yang, "The Comparative Chemistries of Platinum Group Metals and Their Periodic Neighbors in Marine Macrophytes."

Master of Science Degrees

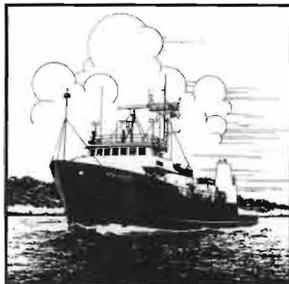
Marine Biology

Abbey L. Rosso

Oceanography

Brian B. Brown
Alessandra Conversi
Susan M. Gaines
Hyeon Joe
Kenshi Kuma
Michele S. Okihiro

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 analyzer and metal hydride systems; a Beckman amino-acid analyzer; a Hewlett-Packard computerized GC/mass spectrometer and four H/P gas chromatographs with EC, FI detectors; a Perkin Elmer HPLC; a superconducting IBM nuclear magnetic resonance spectrometer; a Leco CO₂ and SO₂ analyzer; a Coulometrics total carbon/CO₂ analyzer; a P/E radio-recording computerized infrared spectrometer; a P/E UV-VIS Lambda 3B spectrometer; a Cambridge S-4 scanning electron microscope with Ortec EEDS II energy-dispersive X-ray spectrometer; an

Hitachi H-500 scanning transmission electron microscope with an Ortec EDS X-ray spectrometer; a Zeiss 9 TEM; a Balzer's freeze etch system; 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 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.

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.

Divng 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.

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 channel, 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 designed

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: they include 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 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.

Oceanographic Instrumentation Tower (1.3 km offshore of Mission Beach). This facility provides a stable platform in 18 m of seawater for making continuous oceanographic and meteorological measurements. The tower has enclosed laboratory spaces, external structures for rigging instruments, and electrical power.

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.

Physiological Research Laboratory Pool Facility. This facility includes a holding pool for large marine mammals 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 routinely broadcast to the fishing fleet as well as to scientific vessels. Western Union (TWX-Telex) 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 Computing Facilities include:

Prime Computer Facility.

Scripps's general-purpose computer center consists of a Prime 750 mini-computer, tape and disk drives, terminals, printers, and plotters. The facility is open 24 hours a day.

SSURF: SIO Supercomputer Users Remote Facility. SSURF provides remote access to the San Diego Supercomputer Center, which is situated

on the UCSD campus. The Super-computer Center connects UCSD 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 most of the major public networks in the country, including ARPAnet and BITnet.

In addition to accessing computers across the country, this facility provides substantial computing capacity for local processing. The computer is a VAX 785 with the VMS operating system. There are several plotters, printers, tape drives, and terminals available around the clock.

Scripps Library. The library has outstanding collections in oceanography, marine biology, and marine technology, in addition to extensive resources in atmospheric sciences, ecology, fisheries, geology, geophysics, and zoology. The library currently receives more than 3,700 serial titles and has more than 200,000 volumes, including an extensive technical reports and translations collection, and a rare book collection featuring accounts and journals of famous voyages of 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 Pier. The 305-m pier serves as a launching site for small boats used for local oceanographic work, provides space for on-site studies, and supports the seawater system that supplies the aquaria and laboratories.

The pier, originally constructed in 1916 with funds provided by Ellen Browning Scripps, is currently being replaced. The new pier, which will be 2 m wider and 15 m longer, is being built immediately to the south

of the existing structure. It will provide increased seawater flow for the support systems at Scripps and improved boat launching and sampling facilities.

Scripps Satellite Oceanography Facility. This facility enables oceanographers to receive and process satellite imagery. Data transmitted in real time by the NOAA and NIMBUS 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. Current applications include tracking of drifting buoys via the ARGOS data collection system, near-real-time support of research vessels and aircraft by remote detection of chlorophyll concentrations, and sea-surface temperature determination. A four-day course, taught every quarter by the facility staff, gives potential users an overview of the available tools as well as several hours of hands-on experience.

Seawater System. Pumps located on Scripps Pier deliver seawater to the laboratories and aquaria of Scripps and the Southwest Fisheries Center. The seawater system uses three high-speed sand filters and two concrete storage tanks with a total capacity of 439,060 liters. Delivery capacity is 5,300 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 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.



Sample of *Sebastes constellatus*, the starry rockfish.

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

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

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

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

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

During the past year ODF has accomplished several goals. Dr. James H. Swift was appointed scientific director of the group. Dr. Swift directs ODF activities, and plans to offer researchers hands-on experience with advanced equipment for collecting oceanographic data.

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.



Fish fossil in a concretion from Belem, Brazil.



Center aisle in the Marine Vertebrates Collection.



Fish specimens in glycerine with skeletons stained, and soft tissue cleared.

Thomas Wayland Vaughan Aquarium-Museum. The aquarium-museum helps to increase public understanding and appreciation of the ocean through 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 toured 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. Located across La Jolla Shores Drive on the knoll currently occupied by the Scripps radio station, the new building will be 2½ times larger than the present one. The aquarium-museum is expected to cost \$8.6 million excluding parking and roads.

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

Underwater

Research Areas.

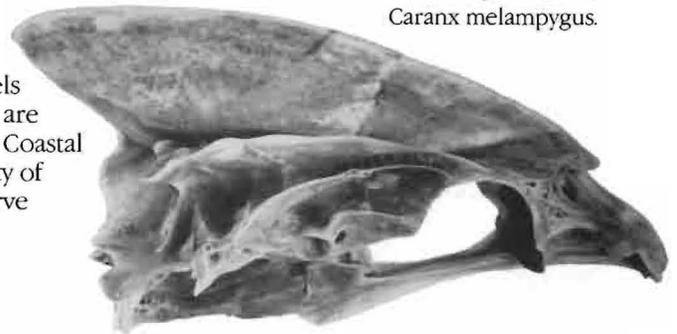
These areas include the following two parcels adjacent to Scripps that are also part of the Scripps Coastal Reserve of the University of California Natural Reserve System.

Scripps Shoreline Reserve. Scripps Shoreline Reserve consists of a 100-acre tract of seashore and ocean where marine plants and invertebrates are protected for scientific purposes. Employees and students of the university may collect from this area with a permit. This reserve is also identified by the California Department of Fish and Game as the San Diego Marine Life Refuge.

Scripps Submerged Land Area.

This area of approximately 3.25 km² is leased by the University of California from the city of San Diego. It lies seaward and to the north of Scripps and includes the head of the Scripps Submarine Canyon.

Cranium of blue jack, Caranx melampygus.



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 III 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 furnishes a wide variety of services from the staffing of cruises (Sea Beam operators), to data processing, distributing, and archiving. Navigation, depth, magnetics, and Sea Beam data are computer-processed for entry into the digital data base and for production of cruise reports and plots. A multidisciplinary index of all samples and measurements made on major Scripps cruises is also maintained by the data center.

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 65,000 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 mid-water trawls. The major emphasis of the collection has been in the north-eastern Pacific, but an increasing number of samples are also available from other oceanic and continental slope regions. The collection includes identified specimens for some of the major taxonomic groups. Samples are supplemented with physical and chemical data.

Marine Vertebrates. This collection contains approximately 2.5 million specimens, with over 3,800 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 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 Chief of the Da-

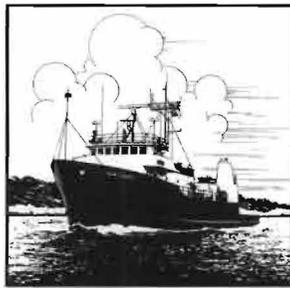
tums and Information Branch, James R. Hubbard, C-233, NOAA/NOS, 6011 Executive Blvd., Rockville, MD 20852. The Marine Life Research Group has kept a tide gage on Catalina Island since 1978; daily records are available by writing Arnold W. Mantyla, A-030, Scripps Institution of Oceanography, La Jolla, 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 Joint Oceanographic Institutions, Inc. and Texas A & M University.

Appendixes



APPENDIX A

Publications

Introduction

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 1987. 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 Munnopsidae. 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 37-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 1986 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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APPENDIX B

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Academic Staff—July 1, 1986 to June 30, 1987

*All symbols and abbreviations are listed at
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 Peter F. Worcester, IGPP, Oceanography
 † Yuan Xiaojun, ORD, Climate Research
 Jagdish S. Yadav, CS, Detector Cosmic Rays
 A. Aristides Yayanos, PRL, Physiology
 Bernard D. Zetler, IGPP, Oceanography
 * Claude E. ZoBell, MBRD, Marine Microbiology
 Mark A. Zumberge, IGPP, Physics</p> | <p>AM—Aquarium-Museum
 AMES—Applied Mechanics and Engineering Sciences Department
 CS—California Space Institute
 CCS—Center for Coastal Studies
 DO—Director's Office
 DSDP—Deep Sea Drilling Project
 D-SIO—Department of the Scripps Institution of Oceanography
 EECS—Electrical Engineering and Computer Sciences Department
 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</p> |
|--|--|---|

APPENDIX C

Awards and Honors

Dr. George E. Backus Received the John Adam Fleming Medal from the American Geophysical Union.

Dr. Andrew A. Benson Received the American Oil Chemists' Society Research Award from Supelco.

Dr. Harmon Craig Received the Arthur L. Day Prize and Lectureship from the National Academy of Sciences.

Deep Sea Drilling Project The staff of the Deep Sea Drilling Project received the Meritorious Public Service Award from the National Science Foundation.

Dr. Charles D. Keeling Elected a Fellow of the American Academy of Arts and Sciences.

Dr. Günter W. Lugmair Received the George P. Merrill Award from the National Academy of Sciences.

Dr. William A. Nierenberg Received the Delmer S. Fahrney Medal from the Franklin Institute.

Dr. Roger R. Revelle Received the 1986 Balzan Prize from the International Balzan Foundation of Milano, Italy.

Scripps Institution of Oceanography Awarded the Distinguished

Achievement Award at the 1987 Offshore Technology Conference.

Dr. Richard C. J. Somerville Elected a Fellow of the American Meteorological Society.

James R. Stewart Received the Undersea Medical Society's Craig Hoffman Memorial Award for 1986.

Received the 1986 Leonard Greenstone Award from the International Conference on Underwater Education and the National Association of Underwater Instructors.

Dr. James J. Sullivan Elected to the Board of Directors of the Marine Division of the National Association of State Universities and Land Grant Colleges. Elected to the Executive Committee of the National Council of Sea Grant Directors.

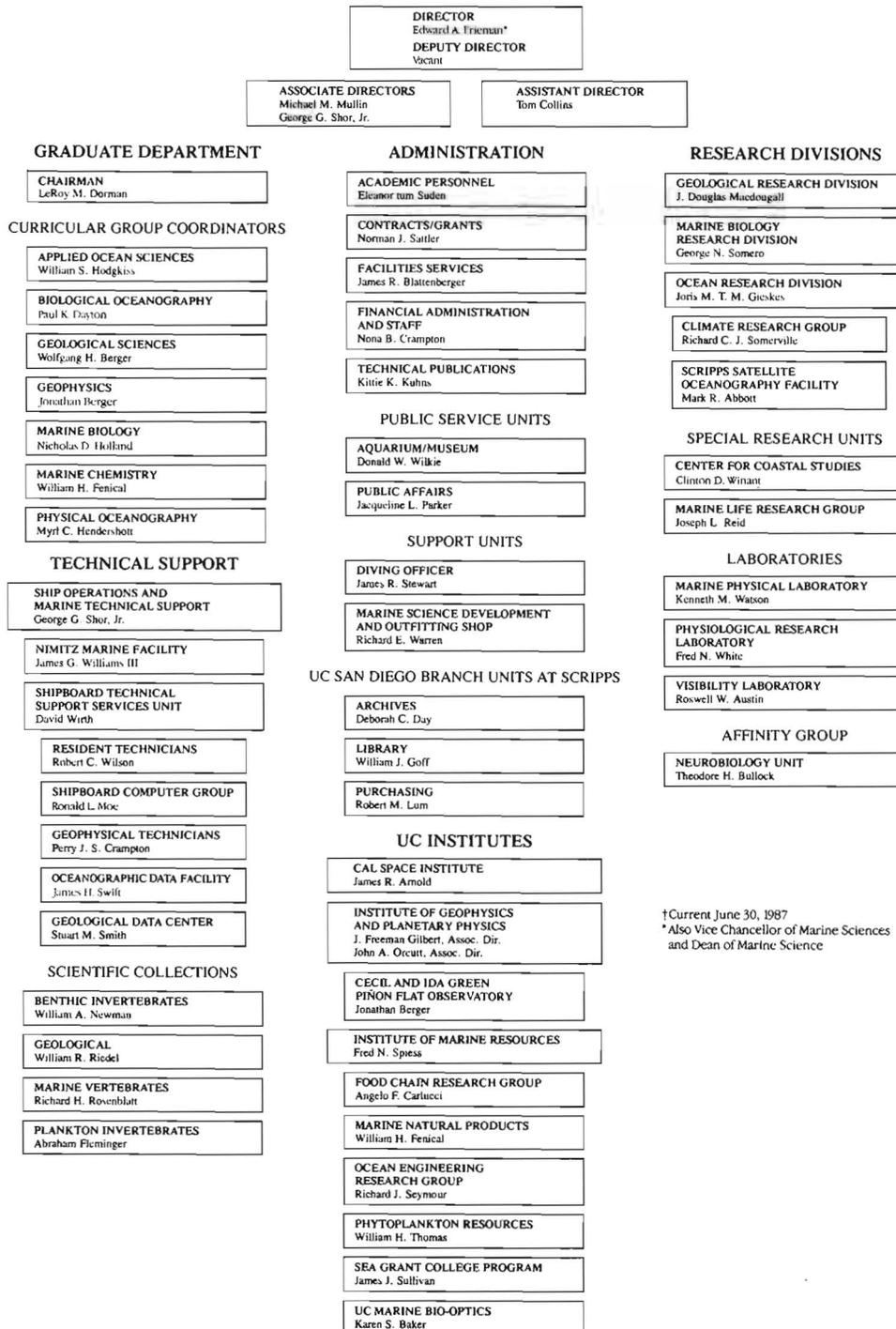
Dr. Lynne D. Talley Awarded a National Science Foundation Presidential Young Investigator Award.

Dr. Mia J. Tegner Named Distinguished Alumna of the Year by the UCSD Alumni Association.

Dr. Claude E. ZoBell Received the Distinguished Alumnus Award from the American Association of State Colleges and Universities.

APPENDIX D

Organization †



†Current June 30, 1987
*Also Vice Chancellor of Marine Sciences and Dean of Marine Science

APPENDIX E

Financial Support *

State and Federal Agencies

California, State of

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

United States

Commerce, Department of
 National Oceanic and Atmospheric
 Administration
 Defense, Department of
 Air Force
 Army, Department of the
 Army Corps of Engineers
 Navy, Department of the
 Engineering Logistics Office
 Naval Ocean Systems Center
 Naval Sea Systems Command
 Office of Naval Research
 Energy, Department of
 Health and Human Services, Department of
 National Institutes of Health
 Interior, Department of the
 Minerals Management Service
 National Park Service
 U.S. Geological Survey
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 National Science Foundation

Foundations/Corporations/ Organizations

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APPENDIX F

Current Funds

	Agency	Expenditures*	Percentage of Total
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Robert Weir Owen			
Charles H. Owsley			
Jacqueline L. Parker			
Jeanne Munroe Perrone			
Martha L. Peterson			
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Dr. Fred and Sally Spiess			
Dr. Robert H. Stewart			
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James and Jennye Wedeking			
Cynthia E. and Edmund Wilford			
Dr. Edward L. Winterer			
Alfred A. Wydler			
Dr. Bruno H. Zimm			
Dr. Claude E. ZoBell			
	Federal Government		
	National Science Foundation	18,105,543	29.09
	Navy, Department of the	14,504,750	23.31
	Commerce, Department of	2,610,876	4.20
	National Aeronautics and Space Administration	1,226,487	1.97
	Health and Human Services, Department of	1,106,995	1.78
	Energy, Department of	784,407	1.26
	Army, Department of the	738,091	1.19
	Interior, Department of the	565,957	0.91
	Air Force, Department of the	423,653	0.68
	Defense, Department of	791	0.00
	Other	<u>177,823</u>	<u>0.29</u>
	Total Federal Government	\$40,245,373	64.68
	State General Funds	13,616,984	21.88
	Private Gifts and Grants	5,824,951	9.36
	Overhead Funds	1,736,355	2.79
	State of California	482,277	0.77
	Endowment Funds	163,948	0.26
	Local Government	199,809	0.32
	Sales and Services	<u>- 36,784</u>	<u>-0.06</u>
	Total Current Funds Expenditures	\$62,232,913	100.00

*Includes overhead

*Anyone interested in making a donation to the institution should get in touch with the Director's Office, A-010, Scripps Institution of Oceanography, La Jolla, California 92093.

APPENDIX G

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IN MEMORIAM

Raymond M. Blei. December 5, 1986. Raymond Blei began working at Scripps in 1946. During his 39 years as a machinist, he developed many Scripps research instruments and devices.

Elizabeth K. Boden. December 20, 1986. Dr. Boden received her Ph.D. from Scripps. She was a researcher in the Marine Biology group from 1954 through 1977. She pioneered research on the bioluminescence of the deep scattering layer.

Gifford Ewing. December 11, 1986. Dr. Ewing was a research oceanographer at Scripps from 1948 through 1966. He served as chairman of the Division of Oceanic Research from 1962 through 1964. He was considered a catalyst in the evolution of space oceanography.

Alfred B. Focke. June 8, 1986. Dr. Focke joined the Marine Physical Laboratory in January of 1954 as a research physicist and served as its director from 1955 until 1959.

Joseph F. Gantner. June 11, 1986. Joseph Gantner was the head librarian of Scripps Library from 1963 through 1966.

Fritz W. Goro. December 14, 1986. Fritz Goro was a regents lecturer and research associate in marine biology from 1969 through 1979. He was an internationally known photographer.

Kenneth M. Green. May 29, 1987. Kenneth Green worked as a carpenter at the Institute of Geophysics and Planetary Physics from 1977 through 1986.

James B. Jordan. February 14, 1987. James Jordan started work at Scripps in 1954 as a marine technician. He was a member of the Marine Biology Research Division, aquarium staff, and Food Chain Research Group during his Scripps career. He retired in 1982.

Rudolph W. Preisendorfer. September 23, 1986. Dr. Preisendorfer was a research mathematician in the Visibility Laboratory from 1952 through 1959, and associate research mathematician from 1960 through 1969. He was also a lecturer at Scripps from 1964 through 1969.

Michael J. Regan. July 4, 1986. Michael Regan served as a utility marine electrician aboard R/V *Melville* for 16 months.

Marston C. Sargent. August 28, 1986. Dr. Sargent joined Scripps as a biology instructor in 1937. In 1946, after serving in the Navy during World War II, he returned to Scripps as an assistant professor. He was scientific liaison officer with the Office of Naval Research at Scripps from 1955 until his retirement in 1970.



All correspondence pertaining to this specific report should be directed to:
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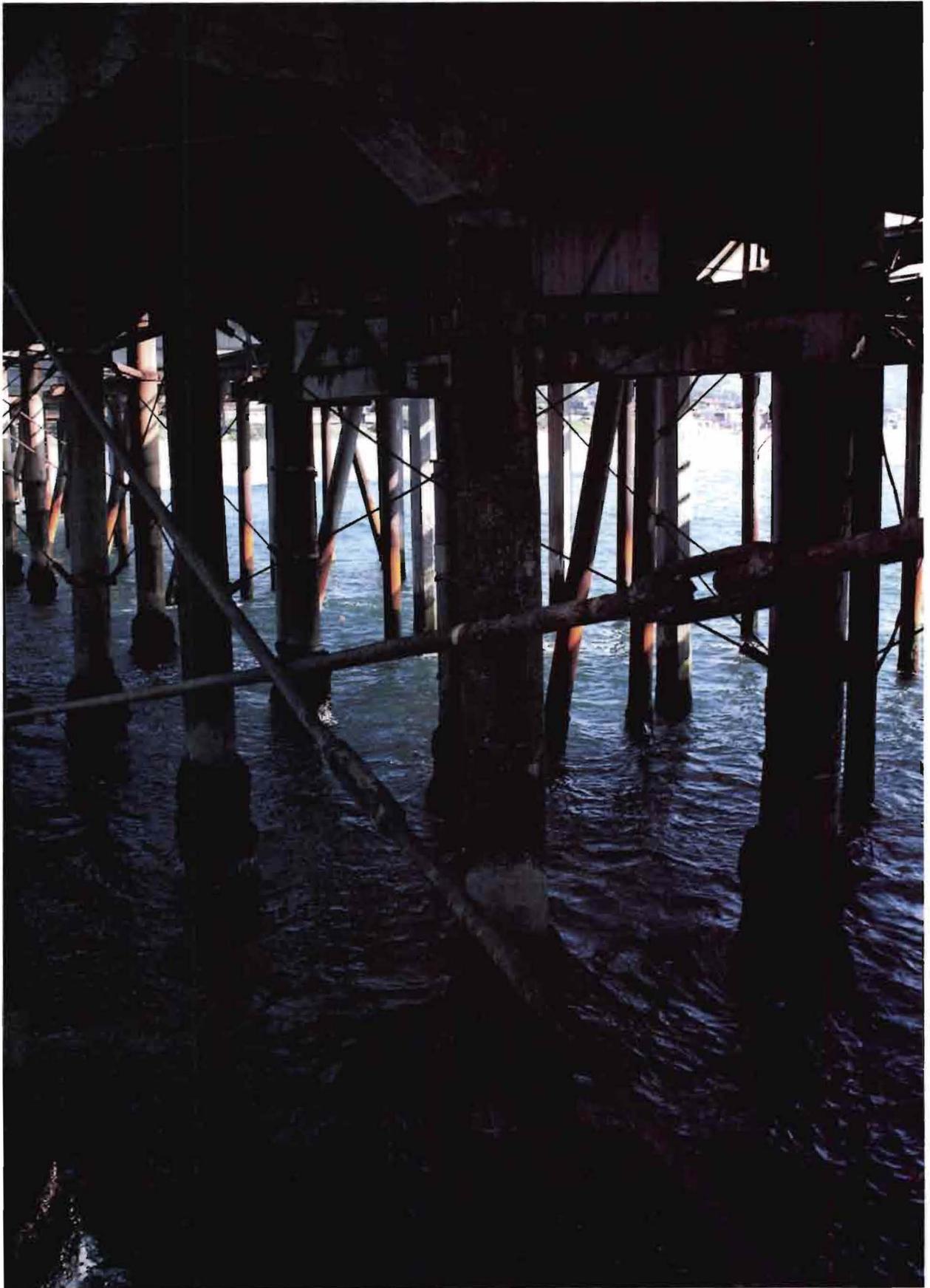
Photomicrograph in crossed-polarized light of a thin section of coarse-grained basalt dredged from a Pacific seamount about 200 km southwest of Scripps. J. Natland

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R/V New Horizon departs San Diego on an expedition.

Inside Back Cover:

Old and new Scripps piers stand together.



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