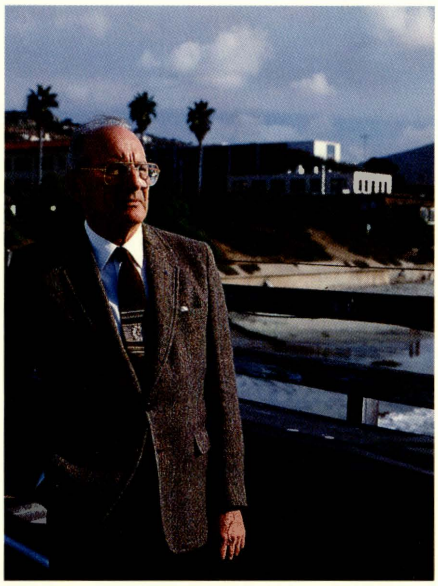
UCSD

Scripps Institution *of* Oceanography

Annual Report 1985

University of California, San Diego

Dedication



It is said that he made Scripps Institution of Oceanography one of the University of California's preeminent centers of scientific achievement, one of California's major assets, and one of the world's distinguished institutions of learning.

William Aaron Nierenberg was appointed Scripps's seventh director in 1965. He has kept Scripps at the forefront of oceanography and earth sciences by establishing many new research programs and facilities, acquiring new ships, increasing cooperative projects with other institutions and agencies, supervising a five-fold growth in Scripps's budget, and emphasizing the value of computer facilities.

In a long record of service to local, state, national, and international agencies, he has advised government leaders, including the President and the military, on a wide range of science and technology issues. He is a member of both the National Academy of Sciences and the National Academy of Engineering.

A pilot, a musician, a linguist, an educator, a gardener—Prof. Nierenberg is a scientist-statesman who has a capacity to bring his intense interests and broad experience to bear on issues that include but transcend marine science and technology.

His years have not slowed his rapid-fire speech or his inquisitive mind, but instead have propelled him into ever-growing areas of scientific concern. In July 1986, Prof. Nierenberg will retire as director to continue his research and teaching at Scripps. Few men have had more of an impact on the institution; his contributions will long be remembered.

Eleanor S. ten Broeke

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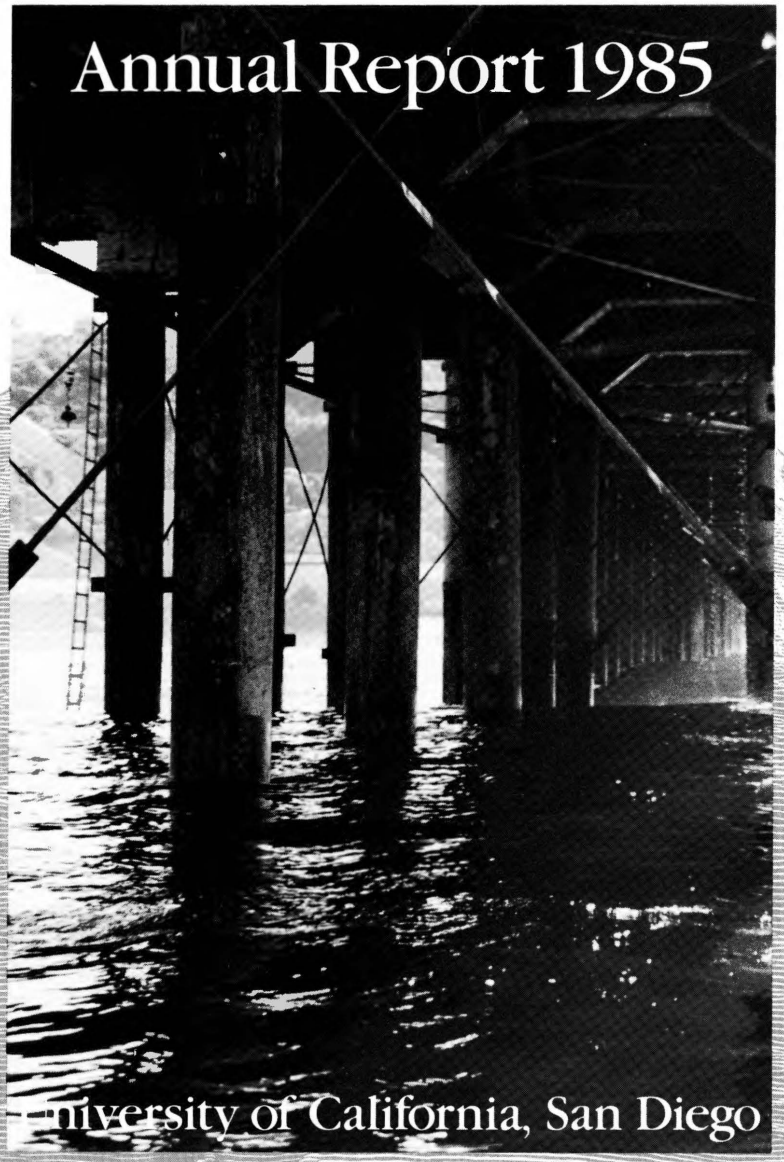

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Contents

Introduction

Since this is the last foreword I write as director, I will violate precedent by not confining myself to the events of academic 1984-85 but will spill over somewhat into the next year. I also must say that I feel somewhat like a relay runner finishing his lap. I must continue with full vigor to hand the baton to my successor who can continue without loss of momentum.

I had anticipated a quiet and relatively uneventful last year as director, but it has been rather the opposite. For one thing, this year has been much like my first at Scripps, in that it marks a revolution in the computing capacity of the institution. With the advent of the Cray computer at UCSD we have decided to establish our own RUAC (Remote User Access Center) by purchasing our own VAX 750. They are in the process of being installed, and the VAX will eventually replace the PRIME. This is just the beginning of a series of steps that will result in our own supercomputer.

Another long-awaited development is the new pier. Construction is about to start as I write this, and we could not have lasted another year. We are also seeing the last stages in the emergence of the T-29 complex as a finished conference center. With the rearrangement of the buildings and the removal of the road on the edge of the cliff, and the new landscaping, we have indeed created what will be a most useful center while preserving a bit of old Scripps with its lovely cypress trees.

The most exciting event for an oceanographic institution is the acquisition of a new vessel. This year saw the dedication of R/V *Robert Gordon Sproul* as the replacement for R/V *Ellen B. Scripps*. It gave me great pleasure to name the ship in honor of perhaps the greatest president this university ever had.

We also can express our gratitude to the Mellon Foundation for the renewal of our postdoctoral program. It has been one of our most important educational and research interventions and we can only hope that it will continue indefinitely.

One unanticipated development was a five-fold increase in the financial returns of our oldest endowment fund. It would take too long to explain how that happened, but it will make up for the losses we have suffered in our industrial associates program as a result of company mergers. I can only hope that we soon can hear similar news of a gift to replace the aquarium, which is now our most pressing building need.

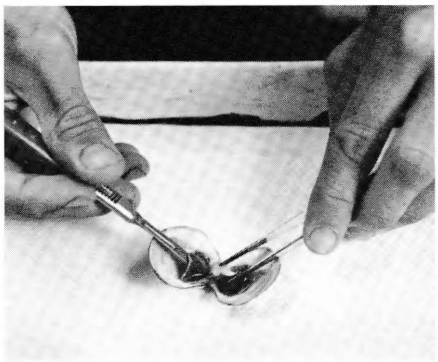
It also has been a great period for honors and awards to our staff. No less than thirteen have been awarded in the last academic year, and the rate seems to be holding. There are too many to be recorded individually on this page, but they are enumerated elsewhere in this report.

On November 28, 1984, Martin Johnson passed away at the age of ninety-one. He served Scripps for more than thirty-five years and as professor emeritus since 1961. Francis Shepard died April 25, 1985, at the age of eighty-seven, after nearly fifty active years on the staff of the institution. Both men were pioneers in their respective fields, and their kind of contribution to oceanography is not likely to occur again.

William A. Nierenberg

William A. Nierenberg, Director
Scripps Institution of Oceanography

Highlights



Symbiosis with Bacteria

Is it possible for animals to survive without eating? Yes. Recently several worms and molluscs without digestive tracts have been found. They obtain most of their nutritional needs from bacteria living inside their tissues. We suggest these bacteria synthesize organic material by fixing carbon dioxide dissolved in seawater, and transfer part of this material to their hosts, thereby nourishing them.

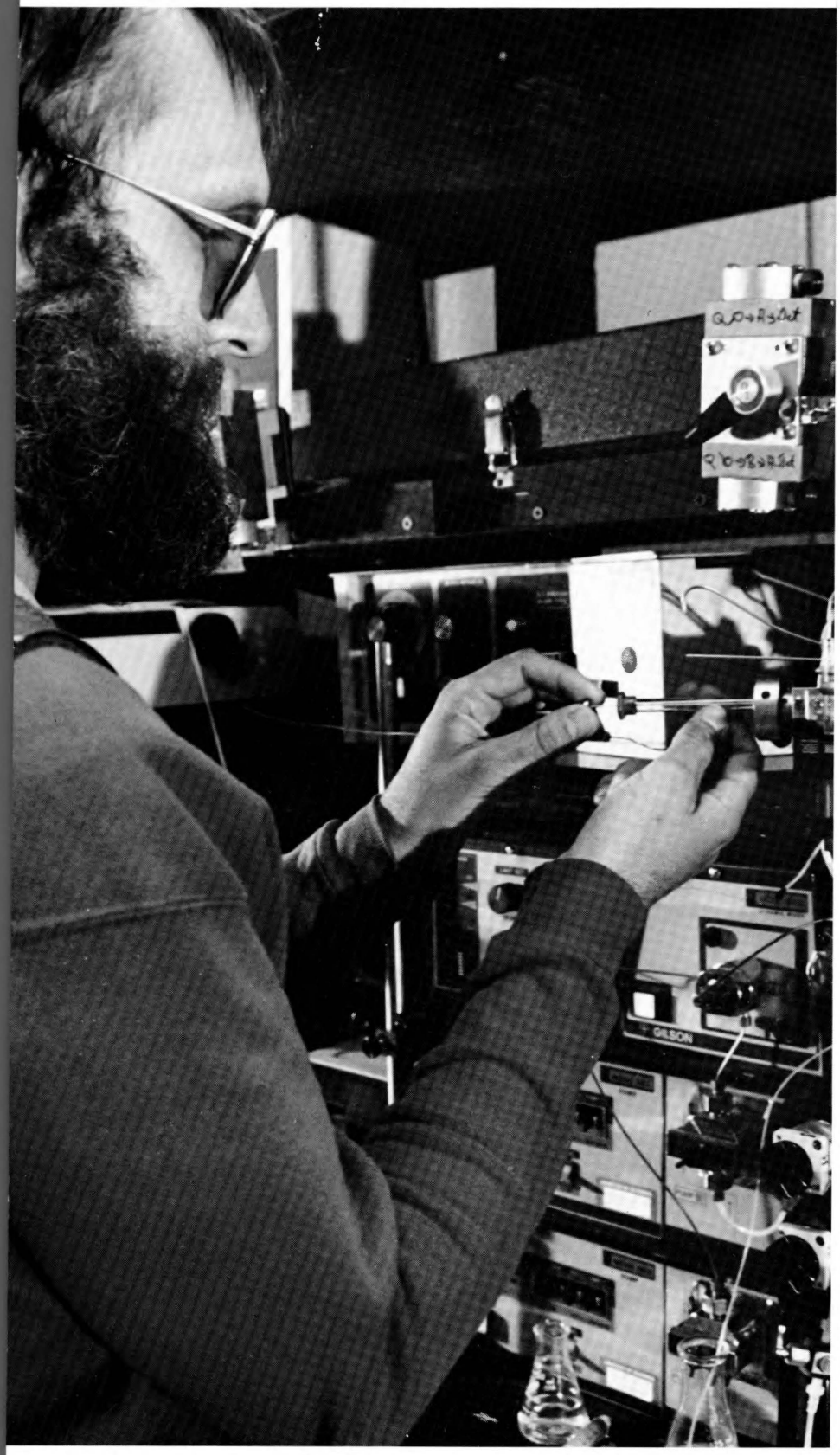
These animal/bacterial symbioses were first discovered in tube worms from deep-sea hydrothermal vents. In vent areas the earth's crust is thin, and the molten magma of the earth's center is close to the surface. Seawater seeps into the crust, is heated (as high as 370°C) by the magma, and is ejected again after a variety of heat-dependent chemical alterations. Dense animal communities are found around these springs and can be supported only by the food produced there. Scientists soon found that high concentrations of chemoautotrophic sulfur-bacteria form the basis of the food chain at the hydrothermal vents. The energy-rich sulfide that is needed to fuel this community is formed during the chemical reactions of the seawater deep in the crust. There sulfate, abundant in seawater, is reduced to sulfide at high temperatures. The bacteria oxidize the sulfide to gain the energy and reducing power they need to fix carbon dioxide.

In clams, mussels, and tube worms, the bacteria are more closely linked to the animals than just being part of the food chain. In clams and mussels, the bacteria inhabit the cells of the gills; in tube worms, bacteria are found inside of cells of a special tissue, the trophosome, that almost fills the entire body. The bacteria synthesize organic material and transfer it to their hosts, thus directly sustaining the hosts.

Soon after this exciting find at the hydrothermal vents, we started searching for other animals with autotrophic bacteria. After all, it would be unusual if such an advantageous process had evolved only in these deep-sea animals. Our search was triggered by an article in *Science*. A clam (*Solemya reidi*) lacking a digestive system had been collected near a Canadian paper mill in an environment with a high sulfide concentration.

The area around sewage outfalls where only primary-treated city sewage is released into the ocean is a biotope which is also characterized by high concentrations of organics and sulfide. And, indeed, the bivalve *Solemya reidi* was also found around southern California outfalls. Our search intensified after biochemical tests and electron microscopy revealed that these molluscs also contained symbiotic bacteria in their gills. So far, we have identified a variety of molluscs and worms from diverse environments with autotrophic bacterial symbionts. The animals exist

Graduate student S. Craig Cary lifts the gills of the clam Lucinoma aequizonata *(opposite page). . . . Dr. Horst Felbeck injects an extract of a clam for final analysis by chromatography (below left). . . . Graduate student Daniel L. Distel prepares the gill tissue of a clam for biochemical analysis (upper right). . . . Radiolabeled compound is applied to isolated clam gills (lower right).*



around other sewage outfalls, in mangrove swamps and organic-rich sediments on Bermuda, in eelgrass beds off the ocean coast, in deep-sea muds, around the coast of Britain, and in all hydrothermal vent areas. In fact, symbiosis of autotrophic bacteria with invertebrates is relatively common.

The bivalves *Lucinoma annulata,* collected in the Santa Barbara Channel, and *Solemya reidi,* from a sewage outfall off Los Angeles, are currently the "work horses" for our symbiosis research. We are using radioisotopic techniques to investigate the carbon metabolism of the animal/bacterial system. We add isotope-labeled components to the animals' metabolism either by placing them in the incubation medium or by injection. In addition, symbiotic bacteria are prepared from the tissues and separated from their hosts for experiments. After the experimental organisms metabolize the radio-labeled compound and incorporate it into their own intermediary metabolites, the experiment is terminated. The diverse components labeled in the organisms' metabolism are then extracted and identified chromatographically. Analyzing the pattern of radio-labeled compounds and their concentrations in the animals or the bacteria reveals how the partners in this symbiosis interact.

Graduate students in my group concentrate on how carbon from food or carbon dioxide is shuttled to the bacteria, and what portions of the nutritional needs are supplied by symbiotic bacteria. Daniel L. Distel is characterizing the bacteria. They have not been identified yet because it is almost impossible to isolate them in culture. He sequences the 16s RNA (a component of the protein-synthesizing apparatus of the bacteria) to learn about the bacteria's taxonomic characteristics. With this technique he can determine (a) whether one or more species form the bulk of the symbiotic bacteria, and (b) whether the bacteria from different individuals or species of animals are identical or closely related.

Graduate student S. Craig Cary uses an entirely different approach to quantify the nutritional needs of the animal/bacterial symbiosis. He developed a system to measure short-time-period growth in molluscs. A laser beam is diffracted in a gap formed by a fixed part and the growing clam shell. The resulting diffraction pattern is analyzed by a computer connected to a diode array. The shape of the diffraction pattern allows conclusions about the shell's daily growth rate. This growth rate is then measured depending on various environmental characteristics like concentration of sulfide, dissolved organics, etc. We hope to deduce the quantitative importance of metabolic sulfide oxidation, uptake of dissolved organic material, and fixation of carbon dioxide from Cary's results.

Other work is being done at Scripps in this field. Dr. George N. Somero's group is investigating the sulfur metabolism of the symbiotic animals—how they deal with the toxic sulfide, and how they gain energy from the oxidation of reduced sulfur compounds. Drs. Alissa J. Arp and Russell D. Vetter are probing how reduced sulfur compounds are transported to the bacteria and how they are metabolized.

This animal/bacterial symbiosis, discovered only a few years ago, has turned out to be much more common than initially assumed. It remains to be seen whether this symbiosis is as important to the hosts as is the algae/invertebrate symbiosis found in coral reefs, many bivalves, and gastropods. Our investigations will elucidate parallel evolutionary developments in deep-sea animals around hydrothermal vents, and in shallow-water animals in naturally sulfide-rich areas. Also, we will clarify how recently occurring sulfide-rich biotopes like sewage outfalls attract these highly specialized symbiotic systems.

Horst Felbeck

Suggested Reading

Felbeck, Horst and George Somero. Primary production in deep sea hydrothermal vent organisms: roles of sulfide-oxidizing bacteria. *Trends in Biochemical Sciences,* v.7, 1982. pp.204-210.

Oceanus, v.27, 1984, whole issue.

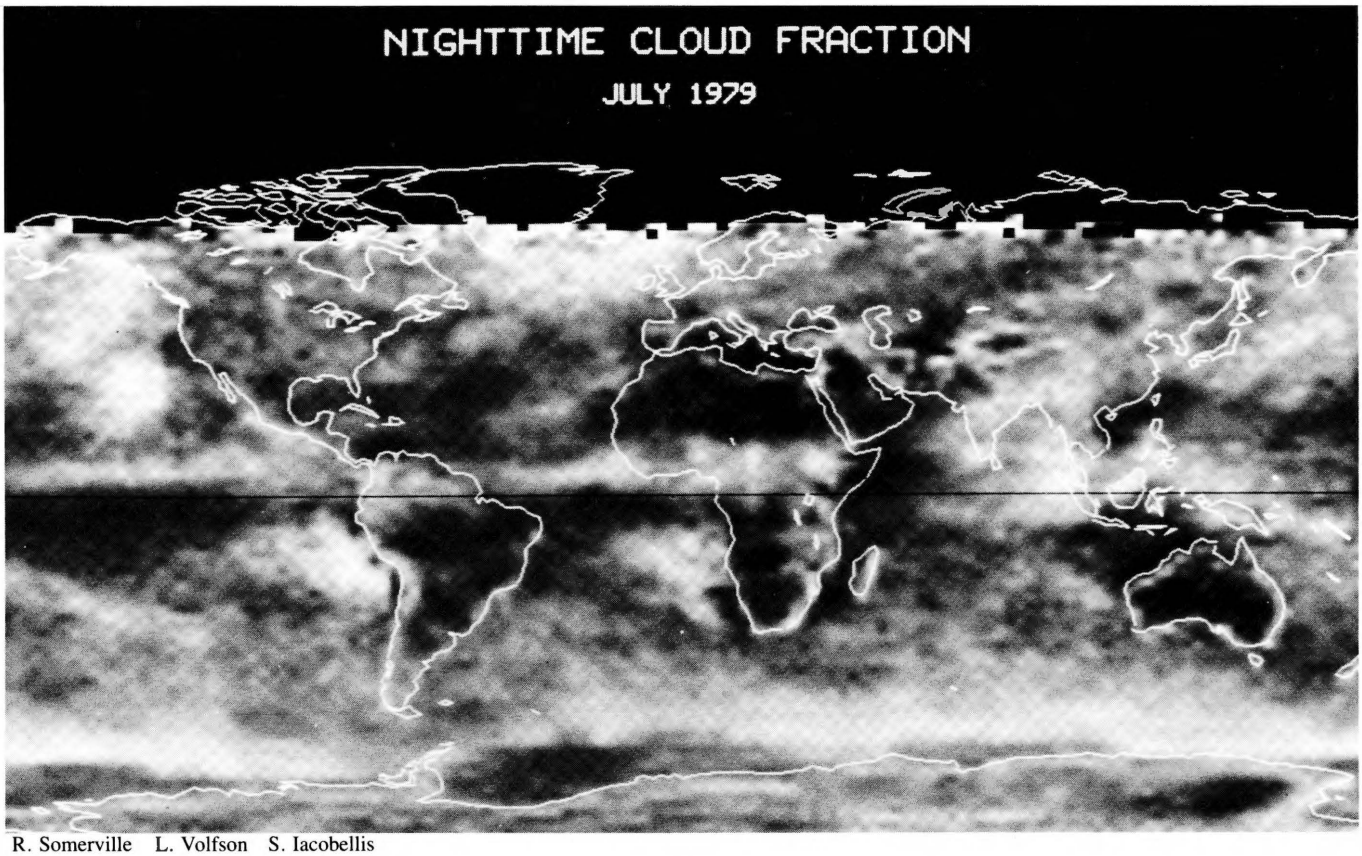
Felbeck, Horst. Sulfide oxidation and carbon fixation by the gutless clam *Solemya reidi:* an animal-bacteria symbiosis. *Journal of Comparative Physiology,* v.152, 1983. pp.3-11.

Do Clouds Control Our Climate?

Mystery still surrounds the precise effect clouds have on our climate; thus the treatment of clouds in conventional climate models may be seriously inadequate. If cloud effects are as strong as recent research at Scripps suggests, considerable uncertainty must characterize the results of even the most advanced climate models. For example, predictions of the climate changes resulting from the burning of fossil fuels, which adds carbon dioxide to the atmosphere, depend strongly on how clouds are modeled. Clouds may amplify changes, or they may act as a giant global thermostat, stabilizing the climate.

The gas carbon dioxide (CO_2), exhaled by animals and absorbed by plants, is released into the atmosphere in great quantities whenever fossil fuels like oil and coal are burned. The increase in atmospheric CO_2 over the last quarter century is shown in the accompanying graph. Dr. Charles D. Keeling's CO_2 research over the past 30 years indicates a strong relationship between atmospheric CO_2 levels and the burning of fossil fuel.

Satellite observations of the global distribution of cloudiness provide crucial data for improving and verifying mathematical models of the climate system.



R. Somerville L. Volfson S. Iacobellis

The greenhouse effect allows the sun's rays to pass to the earth's surface, but restricts heat from escaping into space. According to most present-day climate models, a large CO_2 accumulation in the atmosphere will significantly augment the greenhouse effect. This will cause global warming. The best estimates are that CO_2 buildup could increase the global average temperature 3°C in the next 50 to 100 years. The Climate Research Group is applying climate models to the CO_2 problem to account for cloud influence on this greenhouse effect.

The ocean plays a central role in the CO_2-climate problem. Of course, the ocean is a crucial component of the global carbon cycle. Additionally, as the surface waters of the ocean warm in response to the enhanced greenhouse effect, more water is evaporated into the atmosphere. This water vapor strongly increases the warming of the climate, because water vapor is itself a "greenhouse gas" like CO_2—relatively transparent to sunlight but not to terrestrial radiation. The CO_2 greenhouse effect on the climate of a dry planet would be several times smaller than on the earth, simply because of this water-vapor feedback. Finally, it is water from the ocean that is available for condensation into clouds, which may also feed back on the greenhouse warming by processes that we are only beginning to understand. Thus, ocean-atmosphere interactions lie at the heart of the greenhouse effect.

The potentially great influence of clouds on climate arises from their effects on the transfer through the atmosphere of both incoming solar and outgoing terrestrial radiation. That clouds may dramatically affect surface temperature by both these mechanisms is a matter of everyday experience. Daytime maximum temperatures are considerably lower on cloudy days than on fair ones, and cloudless nights are cooler than overcast ones, other factors being equal. Clouds alter both the planetary albedo, or reflectivity, and the greenhouse effect by helping to trap radiation that otherwise would be lost into space.

The average albedo of our planet is about 30 percent, so only 70 percent of incident solar radiation is actually available to power the climate system. At any given time, clouds cover about half the surface of the earth, but they account for two-thirds of the planetary albedo. We do not know whether the albedo or the cloud cover was substantially different in the distant past. In fact, we have no good explanation of the present-day values of these fundamental climatic parameters. Scientists cannot reliably predict whether or how these parameters are likely to change over the next century, as the concentration of atmospheric CO_2 approaches twice its preindustrial value, and as other atmospheric trace gases, such as methane, also increase and augment the greenhouse effect. It is estimated that the temperature increase caused by doubling CO_2 might be completely offset if the amount of low-altitude cloudiness were to increase simultaneously by 10 percent. This result emerges from a mathematical model sensitivity study—essentially a calcu-

lation of the climatic response to an assumed change in cloudiness.

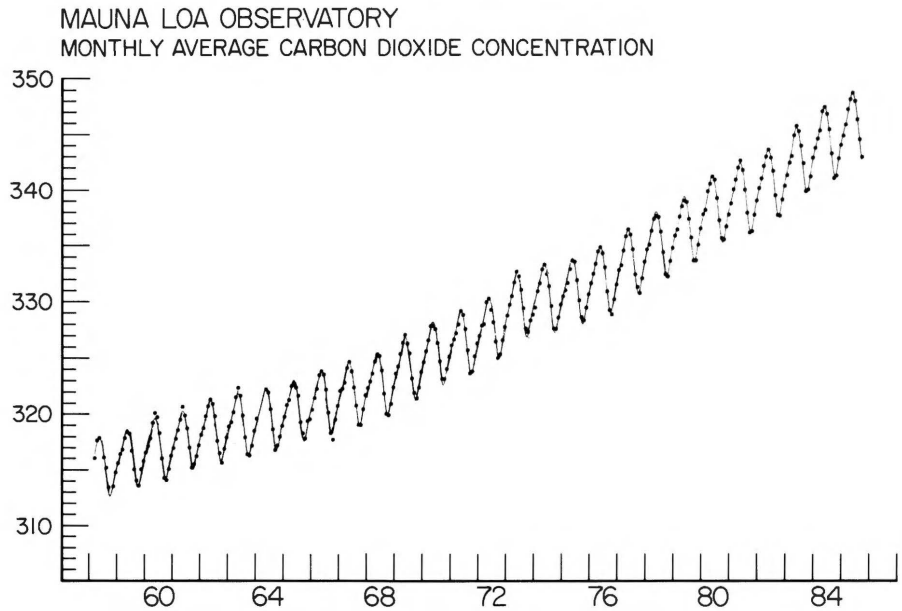
We can easily demonstrate that climate is potentially sensitive to clouds—as in the example above—but it is very difficult for us to model clouds realistically. Climate models incorporate powerful radiative transfer algorithms that could calculate atmospheric heating and cooling accurately, if only the distribution of all the radiatively active atmospheric constituents were known precisely. However, two of the most important constituents —water vapor and clouds—are notoriously changeable and difficult to predict. Even with the most advanced climate models, we cannot simulate all aspects of the present-day global cloud distribution well enough to inspire confidence in cloud forecasts for climates differing significantly from our present one.

Studies have shown that climate can be strongly affected by changes in cloud height as well as changes in cloud amount. Recent study in Scripps's Climate Research Group has raised the additional possibility that the dependence of cloud liquid water content on temperature might alter cloud optical properties enough to substantially influence the global albedo. In the context of the CO_2-climate problem, this process is a cooling mechanism that might partially compensate for the warming resulting from the enhanced greenhouse effect. The quantitative importance of this process is still uncertain, but it illustrates the real possibility that the effect on climate of feedback from cloud radiation may be significant even without changes in cloud amount or height.

Research on cloud-radiation feedback may also offer a quicker payoff for those unwilling to wait a century or so to learn how CO_2 doubling will affect climate. Routine meteorological forecasts are based on numerical weather prediction models. These models are now so complex that they are almost indistinguishable from comprehensive climate models. Short-range atmospheric circulation forecasts, for a day or so in advance, are relatively insensitive to radiative processes. As the duration of the predictions increases, however, such cavalier physical simplifications become less justifiable. There is now considerable evidence that a one-week forecast may gain significant accuracy from more realistic treatments of cloud-radiation interaction, and improvements in modeling clouds and their effects are likely to gradually enhance the predictive skill. If research on modeling cloud effects leads to improvements in one-week forecasts, there should be substantial benefits to weather-sensitive sectors of the economy.

Climate theory, rather than numerical weather prediction, will gain the most from advances in our understanding of cloud-radiation feedback. Sensitivity studies make it clear that cloud feedback could plausibly either double or halve the typical estimated surface-temperature change resulting from increased atmospheric CO_2 concentration. Our ignorance of this feedback is so great that we cannot be sure whether the net effect of all the cloud processes is positive or negative. Perhaps answers will come easier when we have adequate global cloud observations with which to check our theories. Scripps scientists working on satellite remote sensing of global cloud cover may add the building blocks that climate modelers are seeking.

Richard C. J. Somerville



Dr. Charles D. Keeling installed a recording nondispersive infrared CO_2 gas analyzer near the top of Mauna Loa in Hawaii. Continuous records have been kept since 1958. The "Keeling curve" shows the increase in CO_2 in the atmosphere over the last 28 years.

Suggested Reading

Houghton, John T. *The Global Climate*. Cambridge University Press, Cambridge. 1984. 239p.

Revelle, Roger. Carbon dioxide and world climate. *Scientific American*, v.247, no.2, 1982. pp.35-43.

Schneider, Stephen H. and Randi Londer. *The Coevolution of Climate and Life*. Sierra Club Books, San Francisco. 1984. 563p.

Somerville, Richard C. J. and Lorraine A. Remer. Cloud optical thickness feedbacks in the CO_2 climate problem. *Journal of Geophysical Research*, v.89, no.D6, 1984. pp.9668-9672.

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

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

Research Activities

Gerald D. Edwards (above and opposite) aligns a hand-held spectral radiometer with a larger, equatorially mounted version for measuring comparative solar radiance. The video-based, electro-optical camera and filter assembly at the right is monitoring the total sky radiance distribution.

Visibility Laboratory

Scientists in the Visibility Laboratory have been conducting several programs to investigate the structure and behavior of atmospheric and oceanic optical properties. This year theoretical and experimental studies have merged into a more cohesive and mutually supportive context. An example of this cross-fertilization is the continuing use of the FASCAT atmospheric scattering model, developed by Wayne S. Hering, to enhance the atmospheric correction algorithms for Coastal Zone Color Scanner (CZCS) image analysis.

Roswell W. Austin directed major research to determine worldwide distributions of diffuse attenuation coefficient (K_λ) via the interpretation of CZCS imagery. Combining FASCAT and CZCS analytical methods has significantly enhanced understanding and confidence in the laboratory's interpretive capability. The model performance is becoming more efficient, and estimates of K_λ are increasingly reliable. The flexibilities now available in the new model/processing environment make it practical to extend image interpretation methods into regions exhibiting substantial cloud contamination, and to derive reliable approximations for $K(\lambda)$ to within 20 pixels of most cloud edges. This enhanced performance permits quadrupling the usable data base contained within the already extensive archive of CZCS data tapes.

Atmospheric and oceanic experimental measurement programs have been enhanced by new instrument systems developed for or by laboratory technical staff. A new microprocessor-controlled hydrological system for measuring multispectral, subsurface irradiance and radiance profiles was successfully deployed on three major cruises under the supervision of Gerald D. Edwards. This system permits simultaneous measurement in eight spectral bands of the subsurface light fields essential for the in situ determination of $K(\lambda)$ profiles, subsurface reflectance factors, and discrete values of radiance and irradiance.

For atmospheric measurements, a new series of imaging radiometers based on solid-state video imagers is being developed with special emphasis on cloud discrimination and local visibility determinations. Prototypes, tested last year, have been replaced with newer, higher-resolution cameras, and the upgraded systems are nearing completion. It is anticipated that these microprocessor-controlled video systems will have a major impact on the development of climatological and case-study data bases for predicting the optical state of the atmosphere.

Center for Coastal Studies

The Center for Coastal Studies (CCS) serves as an organizational focus for Scripps research in coastal dynamics. The center includes the Shore Processes Study Group, Coastal Dynamics Group, Hydraulics Laboratory, and the Marine Archaeology Program. CCS scientists concentrate on field experiments and related analytical and model studies to unravel the complex interactions of waves, currents, and winds in the coastal ocean.

Dr. Clinton D. Winant finished gathering data for his Gulf of California physical oceanographic study. The joint U.S.-Mexican study of circulation in the gulf produced a comprehensive data set for analyzing this example of a marginal sea. The consistent principle appears to be that unrelated motions take place on either side of this gulf. Dr. Winant is preparing to study circulation in another marginal sea: the Strait of Gibraltar in the Mediterranean will be the subject of a 3-5-year, multi-institutional, multinational experiment.

Dr. Douglas L. Inman, CCS director, studies many aspects of fluid-sediment interactions. He identified several feedback mechanisms that appear to control the temporal and spatial scales of nearbed phenomena. This led to genetic classification of bedforms and to a general theory of bedform response. Coastal study areas include the Nile Delta of Egypt, the barrier islands of the Beaufort Sea coast of Alaska, and the Outer Banks of North Carolina. Graduate student D. Murray Hicks completed his work on sand dispersion from an ephemeral delta.

Dr. Scott A. Jenkins is monitoring an array of lifting bodies that prevents siltation under berthed nuclear submarines at the Mare Island Naval Shipyard. He is studying currents, water, and sediment properties at the Port of San Francisco, and working on a distribution theory for vertical shear stress within the floc layer, which settles in dredged estuarine harbors. Wave forces on a submerged rotating cylinder and tidal dynamics in local lagoons are other interests of Dr. Jenkins.

Dr. Robert T. Guza's group continues work on nearshore waves and currents. Graduate student Steve L. Elgar completed work on shoaling surf and gravity waves. Bispectral analysis played a central part in elucidating the role of wave-wave interactions in the shoaling process. Graduate student Joan M. Oltman-Shay successfully extended high-resolution data-adaptive estimator techniques to pitch-and-roll measurements of ocean waves.

Work of Dr. Nancy A. Bray and graduate student Cynthia A. Paden centered on the thermohaline circulation of the Gulf of California, including air-sea interactions (evaporation, heat and momentum fluxes) that drive the circulation. The study merges meteorological, hydrographic, current, and satellite data into a coherent picture of the annual time-scale circulation of the gulf. In addition, estimates of heat, moisture, and momentum fluxes will be made for comparison with other marginal seas.

During the past year Dr. Reinhard E. Flick and graduate student William C. O'Reilly examined local meteorological forcing of sea-level anomalies on time scales of 1-30 days. Dr. Flick has continued his examination of surf-zone turbulence. He also conducts a regional beach profile monitoring program.

Marine adaptions of the prehistoric peoples inhabiting Southern California Bight coastal regions are reflected in the distribution of underwater sites in nearshore areas, and in seafood remains found in onshore middens. Dr. Patricia M. Masters is recording information on the submerged sites, and over 100 have now been mapped between Point Conception and the Mexican border. Off San Diego County, the sites are found in three localities: nearshore rock or cobble reefs at depths of 3-5 m, the kelp beds, and the heads of submarine canyons. The deeper sites in the kelp beds and the canyons probably represent losses of tools from seagoing craft about 4,000-6,000 years ago. Radiocarbon-dated sites of ca 8,000 years BP on San Clemente Island point to a long history of maritime activities on the southern California coast. Although bony fish remains are not well preserved in the onshore middens from these times, mollusc shell distributions show the peoples' strong dependence on marine food. These findings also reflect the major ecological shift in the mid-Holocene, when sea-level rise slowed, and the vast littoral cells of the bight began to change from rocky, cobbly beaches to the sandy habitats persisting today.

The Hydraulics Laboratory was the site of a variety of experiments by CCS personnel and others at Scripps. The research projects are described elsewhere in this report. The laboratory staff also has conducted model studies of various hydraulic structures in San Diego County, and is currently studying performance characteristics of hopper dredge components for the U.S. Army Corps of Engineers.

Divers Michael C. Clifton (left) and Michael R. Kirk install an experimental current meter and pressure sensor near Scripps Pier. The instruments will measure nearshore waves and currents.

Deep Sea Drilling Project

The Deep Sea Drilling Project (DSDP) is now in its phase-down period. *Glomar Challenger*, which served DSDP and its widespread scientific constituency for more than 15 years, is no longer in service. Work aboard *Glomar Challenger* first embraced a period of broad and world-wide reconnaissance, including involvement of mid-ocean ridges in formation of oceanic crust, establishing a kinematic model for the development of the world's oceans, and opening an entire new science of paleooceanography. Later, DSDP scientists focused on specific problems such as the structure and composition of oceanic crust, evolution of passive margins, processes at active margins, and global oceanic and climatic history. *Glomar Challenger* left as her legacy a new way of thinking about the earth, and a new body of data with which to test these thoughts.

During the first seven years DSDP was a United States effort, funded exclusively by the U.S. National Science Foundation. For its second half, the project became international through bilateral agreements between the U.S. National Science Foundation and organizations representing West Germany, France, Japan, the United Kingdom, and the Soviet Union. Throughout its operational lifetime, DSDP received scientific advice from the Joint Oceanographic Institutions for Deep Earth Sampling, an organization that grew from four charter institutions to 14, including the five non-U.S. representatives. This period of international activity and financial contribution was known as the International Phase of Ocean Drilling.

The International Phase of Ocean Drilling terminated in 1984, at the time the international Memoranda of Understanding lapsed. Phase-down and completion of DSDP work continues. Most of the work that remains is from the international period.

The remaining scientific program is almost exclusively directed toward completion of scientific reporting, and preparing a comprehensive index and the computer-oriented data base. All scientific work is planned to be completed by mid-February 1987, allowing time for the final work under the contract by April 1987, including final data transfer to national repositories, archiving of historical records, and the last entries into the comprehensive index for scientific reports. The final volume of the *Initial Reports of the Deep Sea Drilling Project* should be submitted for publication in late 1986, three years following completion of drilling by *Glomar Challenger*.

Geological Research Division

Interests of scientists in the Geological Research Division (GRD) are wide-ranging, and encompass such diverse topics as earthquake prediction, the petrology of oceanic islands, paleo-oceanography, and atmospheric trace gases. Here only a few of the many projects in the division are discussed; a more comprehensive accounting can be found in the *Scripps Institution of Oceanography Contributions*.

Geochemistry

Dr. Yu-chia Chung carries out geochemical earthquake prediction studies that include a southern California network monitoring program and a joint U.S.-Chinese program. The latter program covers the Xiaguan (SW Yunnan) area for baseline studies and the Beijing area for monitoring studies. Dr. Chung spent three weeks in China sampling geothermal fluids in the two areas. He used a plasma spectrometer to analyze elemental distribution and a gas chromatograph to study concentrations of various dissolved gases. Samples were also collected for helium concentration and isotope variation, i.e., the $^3He/^4He$ ratio. The helium samples are being measured at the Scripps Isotope Laboratory.

Much of the work of Drs. Harmon Craig, John Welhan, and Kyung-Ryul Kim in the Isotope Laboratory this year concerned their 1984 *Alvin* submersible study of the hydrothermal vent fields at 13°N and 11°N on the East Pacific Rise (EPR). On that expedition the new Dionex dual-system ion chromatograph was used for shipboard chemical analysis of vent fluids; for the first time the vent chemistry could be studied during the work at sea. At 12°50′N on the EPR a "black smoker" was discovered and sampled. It had the highest temperature ever observed in a hydrothermal vent—380.5°C. This vent emits the most concentrated fluid observed in submarine hydrothermal systems on the EPR. At 11°N the vent waters represent mixtures of seawater with pure H_2O added and subtracted. Salt contents vary from 125 percent to only 60 percent of the seawater value, providing clear evidence that boiling has occurred somewhere along the hydrothermal solutions' trajectory.

In other activities of the Isotope Laboratory, Dr. Robert J. Poreda continued his field work on basalts and geothermal conditions in Iceland. This is a NATO joint program with Icelandic scientists. He completed his studies of $^3He/^4He$ and deuterium/hydrogen ratios in back-arc basin basalts as tracers for mantle-derived volatiles (helium) and slab-derived components (H_2O). Dr. William Rison spearheaded a renovation of the venerable rare-gas mass spectrometer MICAH, in which a Baur-Signer ion source and a new flight tube and ion collector system were installed (thus producing an essentially new instrument).

Valerie K. Craig continued her work on isotopic tracers of provenance of classic Greek marbles; she and Dr. Craig extended their studies to the marbles of the Taj Mahal, the Dayal Bagh Temple, and the Indian Makrana quarries. These marbles are unique in having the lowest $^{18}0/^{16}0$ ratios so far observed (delta values as low as -13.5 per mil vs the PDB isotope standard), coupled with rather large $^{13}C/^{12}C$ enrichments, similar to the famous Parian marbles. The very low oxygen isotope ratios are most interesting in that they probably reflect the high latitude of India during the metamorphism of these Precambrian marbles, when Indian meteoric waters were probably much lower in oxygen-18 than they are in the continent's present equatorial position.

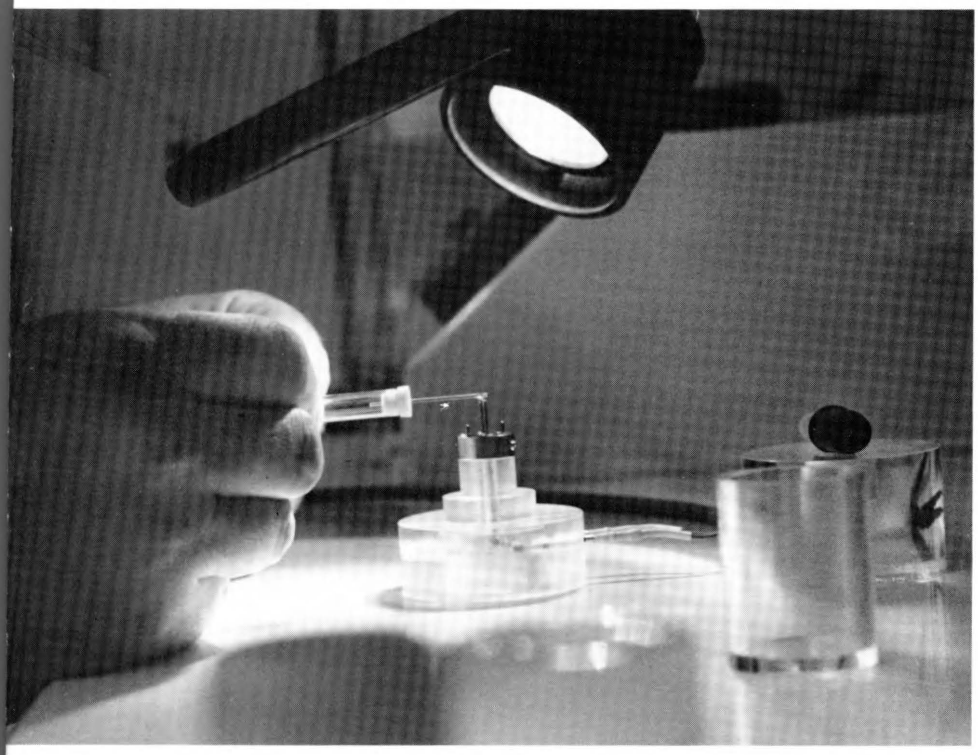
Dr. Devendra Lal, in collaboration with Dr. James R. Arnold and others, has developed a nuclear method to determine the erosion rates of continental rocks. The method, originally proposed by Drs. Lal and Arnold, is based on the in-situ cosmic ray production of ^{10}Be (half-life $= 1.6 \times 10^6$ years) and ^{26}Al (half-life $= 7.05 \times 10^5$ years) in quartz. Quartz is an attractive target material for several reasons: its low aluminum concentration makes it possible to measure ^{26}Al in rocks of exposure ages as short as 10^3 years; its chemical and physical integrities minimize the possibility of contamination by ^{10}Be scavenged from the atmosphere by rainwater; and quartz's ubiquity ensures that it is found in a wide variety of geological settings. By comparing the concentrations of ^{10}Be and ^{26}Al with those expected from cosmic ray production, scientists can obtain the effective cosmic-ray-exposure age of the rock and then translate it into a model-dependent erosion rate. Studies of these isotopes in two surface specimens from California Anza Borrego pegmatites yielded erosion rates of 1.7×10^{-3} and 2.8×10^{-3} cm/yr. A surface sample of quartzite from Allan Hills, Antarctica, had an erosion rate of 1.7×10^{-5} cm/yr. The method may be valuable for studying continental weathering rates and processes, for which no quantitative method has existed.

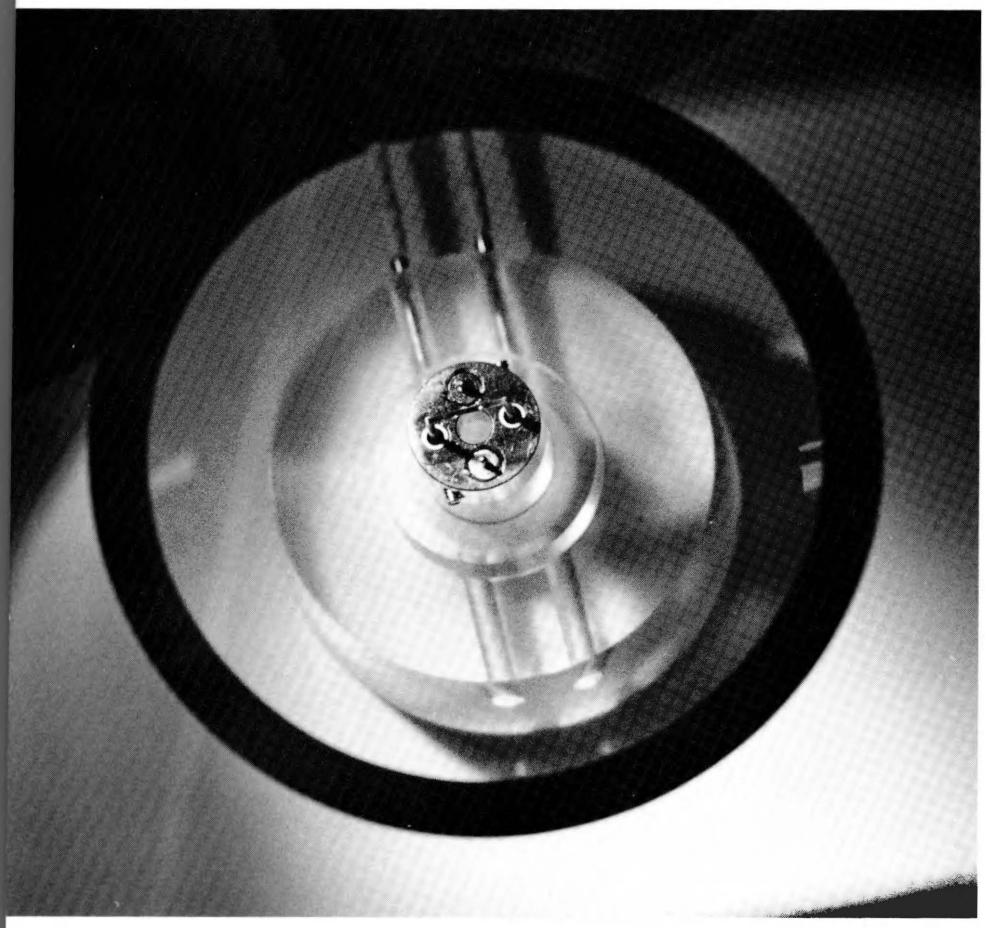
Steps in an isotopic analysis:
After dissolving a rock sample and completing preliminary purification, graduate student Alan M. Volpe carefully loads a solution containing rare earth elements onto an ion-exchange column. The elements neodymium and samarium will be separated during the column procedure.

In the Isotope Geology and Geochronology Laboratory, Drs. Günter W. Lugmair, J. Douglas Macdougall, and associates participated in the "closing" celebration for a new clean laboratory. After several years of preparation, it was finally possible to transfer most chemical work on terrestrial materials requiring pristine laboratory conditions from a UCSD laboratory to Scripps.

Graduate student Qun Cheng, during studies of seamounts, islands, and ridge basalts from the southern Pacific, found that seamounts of the Louisville Ridge have a remarkably small range in isotopic composition for Sr and Nd, in spite of their considerable geographic extent and long eruptive history. This implies a long-term homogeneous mantle source for these rocks, quite different from even most single oceanic islands. Graduate student Wendy K. Hanson began studies of eclogite xenoliths from kimberlites, to clarify the chemical evolution of the continental lithosphere. Graduate student Matthew O. Tanzer completed work on aspects of uranium-thorium series disequilibrium in volcanic rocks. He concentrated on studies of recent lavas from Batur Volcano on the island of Bali, and on rocks from Long Valley, California. These studies gave evidence for possible recharging of the Long Valley magma chamber over the past 100,000 years, and showed that Batur is unusual among island arc volcanoes because radioactive equilibrium between ^{230}Th and ^{238}U is exhibited. This may reflect a lack of fluid-phase U-Th fractionation in this Indonesian island arc volcano. Graduate student Alan M. Volpe examined the trace element and isotopic compositions of back-arc basin basalts from the Mariana Trough and the Lau Basin. He found that the magmas probably are produced from a modified mid-ocean ridge, basaltlike mantle source. Volpe also started comparative study of a possibly arc-related sequence of mafic rocks in northwestern India. Graduate student Richard J. Willis continued studies of gneissic terranes, probably of early Archean age, in eastern and western India.

Chris S. MacIsaac loads a drop of solution containing the highly purified neodymium onto a rhenium filament. A close-up view of the filament assembly before it is inserted into the mass spectrometer (bottom).





Dr. Macdougall spent part of the year at the University of Cambridge, England, where he completed work on a number of manuscripts, including a comprehensive study of isotopic variability among basalts from the East Pacific Rise.

Visiting scientist Dr. H.-G. Stosch completed studies on lower crustal granulite facies xenoliths from the Eifel, West Germany. Sr and Nd isotopic results suggest that the igneous precursors of these granulites differentiated from depleted mantle ~1.5 billion years ago. However, in most of these samples this ancient history is obliterated by a young (<172 million years ago) metasomatic overprint caused by mantle-derived fluids and melts. These findings indicate the strong possibility, at least in similar environments of continental rifting and uplift, that the evolution of continental crust (such as felsic plutonic rocks with mantle Sr and Nd isotopic signatures) may involve metasomatized lower crust as the main source.

In the field of isotopic studies on extraterrestrial materials, Drs. Matthias H. Jungck, Tadashi Shimamura, and Lugmair discovered widespread atomic excesses on the neutron-rich isotope ^{48}Ca in Ca-Al-rich inclusions from the C3 meteorite Pueblito de Allende. These inclusions are thought to have formed during the earliest evolutionary phase of our solar system, some 4.56 billion years ago. The isotopic anomalies in Ca range up to six parts in 10,000 and are similar in magnitude to those previously found for ^{50}Ti. These isotopes are believed to be coproduced by neutron-rich nucleosynthetic processes within stars. Further studies on the correlation of the relative excesses of these two isotopes will help constrain the conditions during their production within stars.

Geophysics

In India, Dr. James N. Brune studied the structure beneath the Bay of Bengal. He and Indian colleagues used observed dispersion of fundamental Rayleigh and Love waves across the Bay of Bengal to Worldwide Standard Seismographic Network and Indian seismograph stations, and found continentlike crustal thickness beneath the bay sediments. They proposed several hypotheses to explain this rather surprising discovery.

Graduate students Allan W. Sauter and Anthony E. Schreiner, working with Dr. LeRoy M. Dorman, observed seismic waves that travel in the waveguide formed by the poorly consolidated sediments on the seafloor. The rapid increase of shear velocity with depth produces strong dispersion in the wave train. Extremely slow seismic velocities in the 40-100 m/sec range were observed. These waves carry information defining the sediment properties to a depth of ~100 m beneath the seafloor.

Oceans and Atmospheres

The CO_2 group (Dr. Charles D. Keeling and associates) has been studying the global carbon cycle through measurements in the atmosphere and oceans, and by modeling these measurements to understand their significance. The data now include not only CO_2 concentrations but also $^{13}CO_2/^{12}CO_2$ isotopic ratios, which were determined in the Netherlands from gas extractions prepared at Scripps.

The most advanced models for time scales less than the mixing times of the important reservoirs resemble the three-dimensional general circulation models that are used to forecast weather. The reservoirs are represented by grid points in these large, numerical models. Drs. Martin Heimann and Keeling have developed an atmospheric model of this type that is based on observed wind velocities from the First Global Geophysics Experiment. Biospheric net primary production at each grid point on land for each month of the year was deduced from very-high-resolution radiometer data from satellites. Drs. Heimann and Keeling can predict the observed seasonal amplitudes in atmospheric CO_2 and $^{13}CO_2$ concentrations at the measuring stations, and the observed latitudinal gradient in seasonally averaged concentrations. Their analysis indicates that the tropical biota source of CO_2 from deforestation and agricultural clearing is small compared to the fossil fuel source.

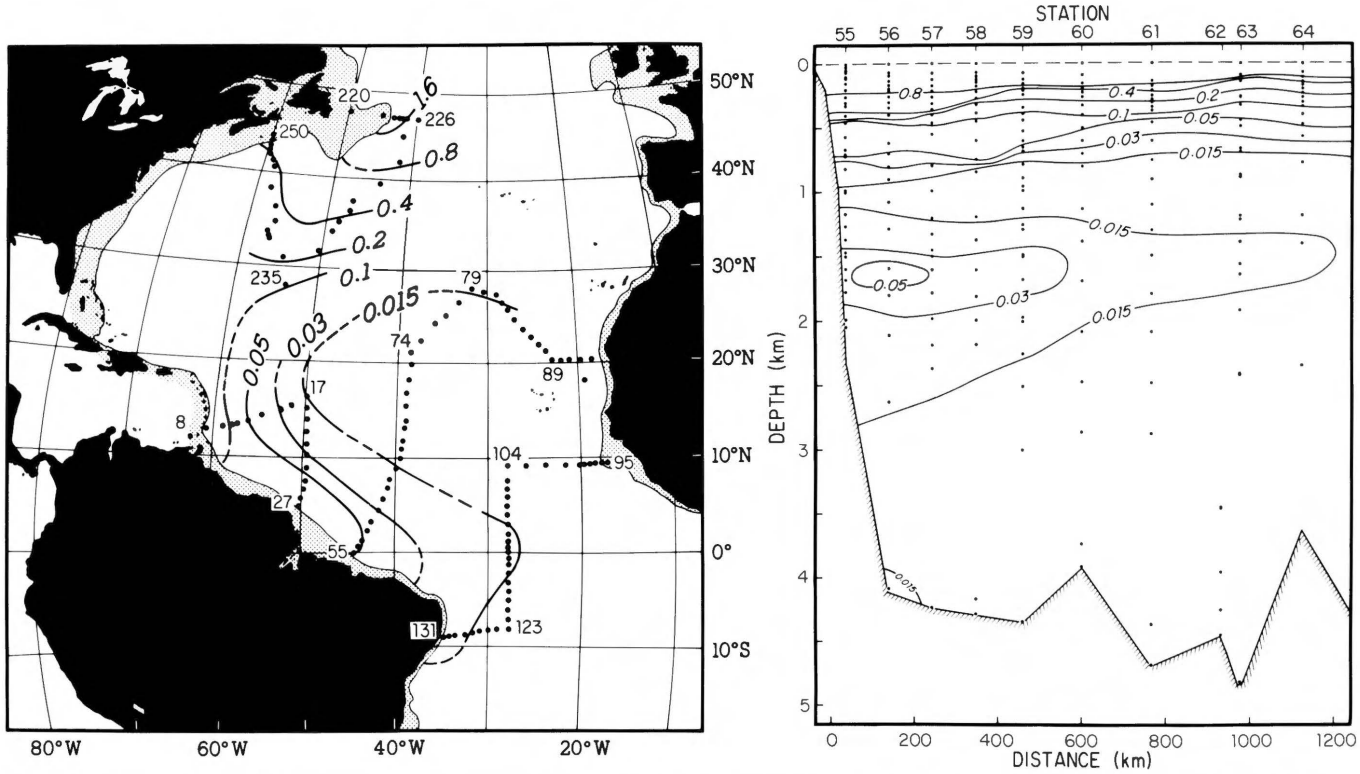
Any prediction of the amount of CO_2 remaining in the atmosphere from fossil fuel combustion must involve an oceanic model. Dr. Robert B. Bacastow, in collaboration with a West German scientist, is developing a world ocean, carbon-cycle model based on the current velocity field from a three-dimensional, oceanic general-circulation model. Included is exchange of CO_2 with a model atmosphere, and chemical changes in the ocean water associated with metabolism of marine organisms. The model distribution of pCO_2 in the ocean agrees with the limited available observations, and predicts the two-dimensional field in regions for which data are sparse or nonexistent. The model also predicts three-dimensional distributions of phosphate, total CO_2, alkalinity, dissolved oxygen, and tracers such as radiocarbon and ^{13}C. Discrepancies between observations and model predictions are used as a diagnostic tool to improve both the carbon-cycle model and the circulation model on which it is based.

Dr. Ray F. Weiss and his research group continue their studies of subsurface ocean circulation and mixing based on the distributions of dissolved atmospheric man-made fluorocarbons. Dr. John L. Bullister completed work on fluorocarbon studies of deep-water and bottom-water formation in the Greenland and Norwegian seas. He then carried out austral summer fluorocarbon measurements aboard the West German icebreaker *Polarstern* in the southern Weddell Sea. At the same time, Frederick A. Van Woy made similar measurements aboard the U.S. Coast Guard icebreaker *Polar Star* in the western Ross Sea. Together with similar Antarctic studies in 1984, this work demonstrates that fluorocarbons are ideal tracers for studying the various mechanisms and rates of bottom-water formation around the Antarctic continent. Graduate student Mark J. Warner has contributed to the development of fluorocarbon tracer research by measuring the solubilities of fluorocarbons 11 and 12 as functions of temperature and salinity.

Dr. Weiss continued his research on the surface water and atmospheric distributions of nitrous oxide, carbon dioxide, and methane in an effort to characterize the oceans' role as a source or sink of these environmentally important atmospheric trace gases. This atmospheric research has focused on the global abundance of tropospheric nitrous oxide (as determined from shipboard measurements and from time-series flask samples collected at several remote sites), which continues to increase at about 0.2% per year and thus contributes to the global "greenhouse" warming of the atmosphere. Most recently, Dr. Weiss's research groups boarded the University of Washington's R/V *Thomas Thompson* to study surface water and atmospheric nitrous oxide, methane, carbon dioxide, and dissolved fluorocarbon across the entire Pacific basin at 24°N.

Paleooceanography

The paleooceanography group—Drs. Wolfgang H. Berger, Robin S. Keir, and Edith S. Vincent—concentrated on reconstructing past atmospheric CO_2 from deep-sea sediments, and on modeling long-term control by the ocean. Part of this effort focused on the effects that recent coral reef growth would have had on deep-sea sediment radiocarbon stratigraphy and atmospheric CO_2. Results were presented at a conference on carbon transfer in the atmosphere, ocean, and terrestrial system. Highlights of these results are (1) that the North Atlantic Deep Water formation apparently was reduced sporadically during deglaciation, and (2) that in the middle Miocene, before the buildup of the Antarctic ice caps 15 million years ago, atmospheric CO_2 content was drastically reduced by the generation of a large reservoir of organic carbon.



Distributions of dissolved atmospheric fluorocarbons in the deep equatorial Atlantic. The figure on the left shows the southward propagation of fluorocarbon 11 concentrations in picomoles per kilogram in the western Atlantic along a density surface that lies at a depth of about 1.6 km. Station numbers are also indicated. The figure on the right shows fluorocarbon 11 distributions on the vertical section extending from station 55 near the South American continent at the equator to station 64 near the Mid-Atlantic Ridge. From these distributions, and the distribution of fluorocarbon 11/12 ratios, waters originating in the Labrador Sea region are shown to reach the equatorial Atlantic as a well-defined western boundary undercurrent, with a transit time on the order of 23 years, and a fivefold dilution by other fluorocarbon-free waters. (Weiss, Bullister, Gammon, and Warner, Nature, *v. 314, pp. 608-610, 1985).*

Petrology

This year Dr. James H. Natland continued evaluating the petrology and volcanic history of the Samoan Islands in collaboration with Dr. James W. Hawkins, Jr., graduate student Elizabeth Wright, and a University of Alaska colleague. Field studies and radiometric ages establish that the Samoan chain is age-progressive—that is, islands are successively older to the west—and that the volcanoes progress through time from tholeiitic to alkalic compositions. Wright's isotopic work confirmed that this sequence represents tapping of less-depleted mantle sources through time, a sequence opposite to that observed in Hawaii. Additional trace-element data support the conclusion that a radically more enriched mantle source is involved at Samoa than at Hawaii.

An extremely elongate volcanic rift zone, produced by deformation of the Pacific Plate along the Samoan Ridge near the Tonga Trench, has promoted near-simultaneous extraction of magmas produced at about 100-km depths along the chain's axis for more than 300 km. This coincidence suggests that Samoa has not been produced by a mantle plume, as scientists have hypothesized for Hawaii, but that the mantle is horizontally stratified with both more-enriched and less-enriched materials beneath all the islands at once. Thus there is no necessary link between the geometrical arrangement of the mantle source regions and the thermal/convective processes that produced the separate Samoan volcanoes.

Dr. Natland also continued his collaboration with Dr. Robert L. Fisher and a Duke University colleague on the petrology of basalts and gabbros from Indian Ocean ridges and fracture zones. A first-order geographical reconnaissance established the presence of several domains having characteristic basalt compositions in the Indian Ocean, each evidently reflecting varying degrees and depths of melting of parental magmas. There is a sharp transition in lava compositions at the triple junction between the Central and Southwest Indian ridges, a transition also reflected in Sr (not Nd) isotopes. Gabbro compositions, surprisingly, reflect crystallization from more differentiated basaltic magmas than any actually sampled, a feature evidently related to the geometry of magma bodies and dike injection zones at spreading ridge segments near the fracture zones.

Marine Biology Research Division

Marine Biology Research Division scientists continue to investigate the biochemical, physiological, cellular, and ecological characteristics of marine plants, animals, and bacteria. Their diverse studies focus on interactions between marine animals and their algal and bacterial symbionts, navigation and predation by sharks in the open ocean, the changes occurring in sperm at the moment of egg contact, the taxonomy of fish from deep-sea hydrothermal vents, and how small marine copepods discriminate between toxic and nontoxic unicellular algae.

Processes for survival in the lowest nutrient areas of the ocean are the focus of scientists in Dr. Andrew A. Benson's laboratory. Dr. Benson and Dr. Masayuki Katayama are studying arsenic and antimony metabolism by algae, which absorb these similar ions in their quest for phosphate. The researchers discovered a novel mechanism for transmission of phosphorus and other essential nutrients from bacteria to algae, involving the transfer of membrane phospholipids from alga to bacterium and vice versa. The transference of membrane components may be an important contribution to symbiotic relationships in the sea.

Dr. Francis C. Knowles is exploring the molecular evolution of hemoglobin in his studies of hagfish, rattail fish, and other deep-sea animals. These animals' adaptations to high-pressure environments give their hemoglobin proteins unique structural and functional properties. In studies of adaptations to acidic and alkaline environments, Dr. Judd C. Nevenzel examined the acid-sensitive lipid compositions of gills of aquatic organisms. Dr. Nevenzel is investigating the effects of acid rain and selection of species resistant to acidic environments.

Dr. Lanna Cheng continues to study sea-skaters, *Halobates* spp., the only open-ocean insects. In collaboration with colleagues in Hawaii and Germany, she has found that *Halobates micans* in upwelling areas of the Atlantic Ocean contain high concentrations of cadmium and other heavy metals. These metals may be transferred up the food chain to *Halobates'* major predators, seabirds. In collaboration with Dr. Ralph A. Lewin and others, Dr. Cheng also works on ecological aspects of *Prochloron*-didemnid symbioses in coral reef areas.

Dr. Horst Felbeck's group continues to investigate carbon metabolism in symbioses between bacteria and invertebrates from sulfide-rich environments, including mangrove swamps and hydrothermal vents. The mechanisms of carbon dioxide fixation and the nature of translocation products between bacteria and host are major focuses of the research. (See Highlights Section)

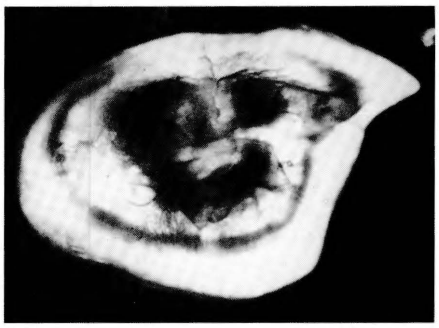
Research by Dr. Francis T. Haxo focuses on the function and distribution of algal chloroplast pigments. Action spectrum studies for photosynthesis in the widely distributed coccolithophorid *Emiliania huxleyi* now show that its major carotenoid, 19-hexanoyl-oxy-fucoxanthin, functions as an efficient light-harvesting antenna for photosynthesis. In a study with a University of Trondheim colleague, Dr. Haxo identified this xanthophyll in the anomalously pigmented red tide dinoflagellate *Pthychodiscus (Gymnodinium) breve*, suggesting an important light attenuation role and similar fucoxanthin derivatives in the sea.

Dr. Mark E. Huntley and graduate students Victor H. Marin and Paul F. Sykes found that the copepod *Calanus pacificus* rejects a number of commonly occurring dinoflagellates as food. This rejection appears to be mediated by a variety of chemical compounds, which cause abnormalities in copepod physiology ranging from regurgitation to elevated heart rate and loss of motor control. They also work on the feeding behavior and distribution of the Antarctic salp, *Salpa thompsoni*, which dominated the zooplankton of the Scotia Sea and Antarctic Peninsula region in early 1984. These are the first physiological studies on salps outside the tropics and subtropics.

Dr. A. Peter Klimley is investigating the impact of the white shark, *Carcharodon carcharias*, on seal and sea lion populations in northern California. To obtain a predatory budget for a free-swimming shark, he designed and built two types of ultrasonic telemetry transmitters. The first is internal, for indicating ingestion of warm-bodied prey by temperature sensing; the second is external, for recording the behavior (accelerated swimming, surfacing) associated with a predatory attack. The predatory budget will be combined with a population estimate. A long-term pinger was built to test whether the spatial distribution of sharks correlates with that of pinnipeds. Dr. Klimley described the autoecology of the shark based on a computer data base of capture records. In a study of orientation/navigation mechanisms used by pelagic sharks to swim a straight line in the open ocean and to home to islands and seamounts, he is developing a miniature swimming direction sensor.

Work on unicellular algae by Dr. Ralph A. Lewin continues to yield surprises. *Prochloron* (a green algal prokaryote) samples were collected in Palau Islands and are being analyzed by colleagues elsewhere. Dr. Michael E. Huber is using electrophoresis to investigate various clones of green eukaryotic flagellates in the genus *Tetraselmis* (widely used as food for cultured zooplankton). Of 65 pure cultures, most fall into one of two classes.

Dr. Richard H. Rosenblatt inspects a specimen of the newly described eel-pout from a hydrothermal vent area. An otolith (ear bone) from a specimen showing possible growth rings (bottom).



Surprisingly, in many cases triple isozyme bands were observed, indicating a diploid genetic complement (most other green flagellates are haploid). This suggests that in this family (Prasinophyceae) there may be sexual reproduction, although it has never been observed directly. Certain small nonflagellate phytoplankton algae *(Nannochloropsis)* can float in seawater because they produce intracellular lipids, which constitute up to half of their cellular dry weight, and which increase their buoyancy. Half of this lipid consists of straight-chain hydrocarbons. Because the world needs renewable fuel sources, such algae have economic potential.

Dr. Richard H. Rosenblatt, together with Dr. Daniel Cohen, Los Angeles County Museum of Natural History, has prepared an account of fishes living in hydrothermal vents along the East Pacific Rise. Specimens of eel-pouts (Zoarcidae) from vents at 13°N and 20°N are being described. They represent two species of a new genus apparently limited to vent systems. Otoliths from these specimens show clear, regular growth rings, which is unexpected because the fishes live in a continuously dark, constant-temperature environment with a steady food supply.

Investigators in Dr. George N. Somero's laboratory continued their studies of the biochemical adaptations that enable marine organisms to prosper in diverse marine habitats. A major line of research involves animals from sulfide-rich habitats (the deep-sea hydrothermal vents and sewage outfall areas, which possess sulfur bacteria as symbionts). Studies by graduate student Mark A. Powell showed that the unusual, gutless clam, *Solemya reidi*, has biochemical systems for oxidizing the energy-rich, yet toxic molecule hydrogen sulfide. The gills of this clam contain a heretofore unknown type of organelle, termed a "sulfide oxidizing body," which may convert sulfide into a nontoxic form of sulfur, which then is fed to the sulfur bacteria symbionts. Dr. Russell D. Vetter investigated sulfide metabolism in marine animals and, along with Dr. Alissa J. Arp, studied the mechanism of sulfide binding to the hemoglobin molecule of the deep-sea tube worm, *Riftia pachyptila*. A major portion of the sulfur metabolism work was carried out during a five-week expedition to the Galápagos hydrothermal vent site.

The other major lines of research in Dr. Somero's laboratory involve study of how marine organisms' proteins are changed, in type and quantity, to fit the organisms to their particular environmental conditions. Graduate student Susan J. Roberts extended her studies of the interactions between the enzyme phosphofructokinase and the filamentous protein, actin. These interactions may be important in the regulation of muscle metabolism, and may help determine the sensitivity of this enzyme to temperature and pressure. Studies of the biochemical consequences of fasting in fishes were continued by graduate student Mary Sue Lowery. Allen G. Gibbs's doctoral studies focus on pressure effects on a membrane-localized enzyme. Changes in muscle biochemistry that occur during exercise conditioning in marine fishes are being carried out by graduate student Sandor E. Kaupp.

Dr. Joan G. Stewart studied processes that regulate competitive growth between nearshore algae and sea grasses. These processes adapt each to dominance above and below a shared boundary. She found that although the mechanisms are similar on San Diego rocky beaches to those on beaches studied elsewhere, the proportional influence differs here. She also compared naturally exposed and experimentally scraped surfaces to explain how taxa become established, or why they do not persist under varying conditions. These data indicate the complexity of interacting factors that maintain and interrelate plant associations. In contrast to systems that have been described in the northern California coast, Dr. Stewart found that physical factors affect species composition and relative taxa abundances more than do biological interactions.

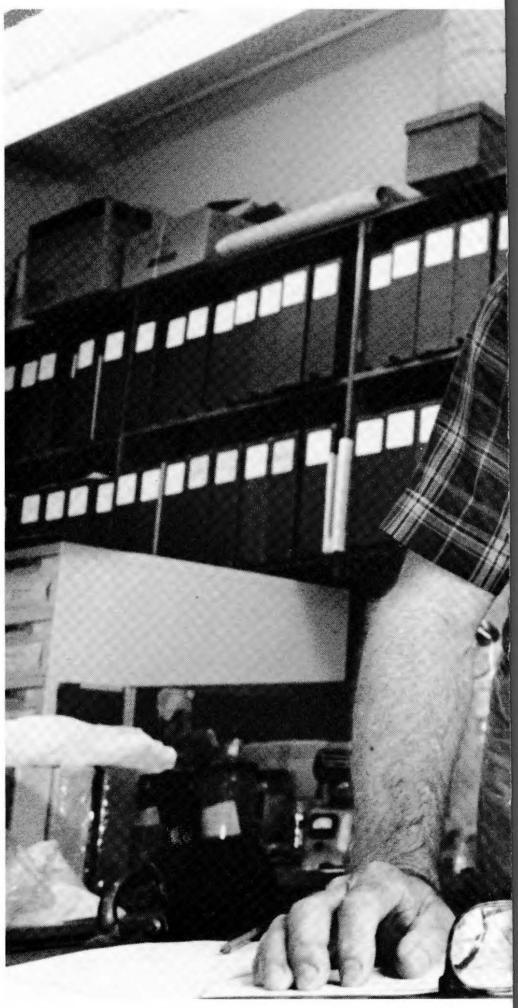
Dr. Frederick I. Tsuji and collaborators cloned the cDNA for the lumines-

cent protein aequorin. The protein emits a blue light in the presence of a trace amount of calcium ions, using coelenterazine as a functional chromophore. Sequence analysis of the cDNA shows that the protein consists of 189 amino acids, with a molecular weight of 21,400. The protein has three calcium binding sites, which are homologous to those found in calmodulin, parvalbumin, and troponin C. The sequence also showed the presence of three hydrophobic regions at which the protein may interact with its functional chromophore.

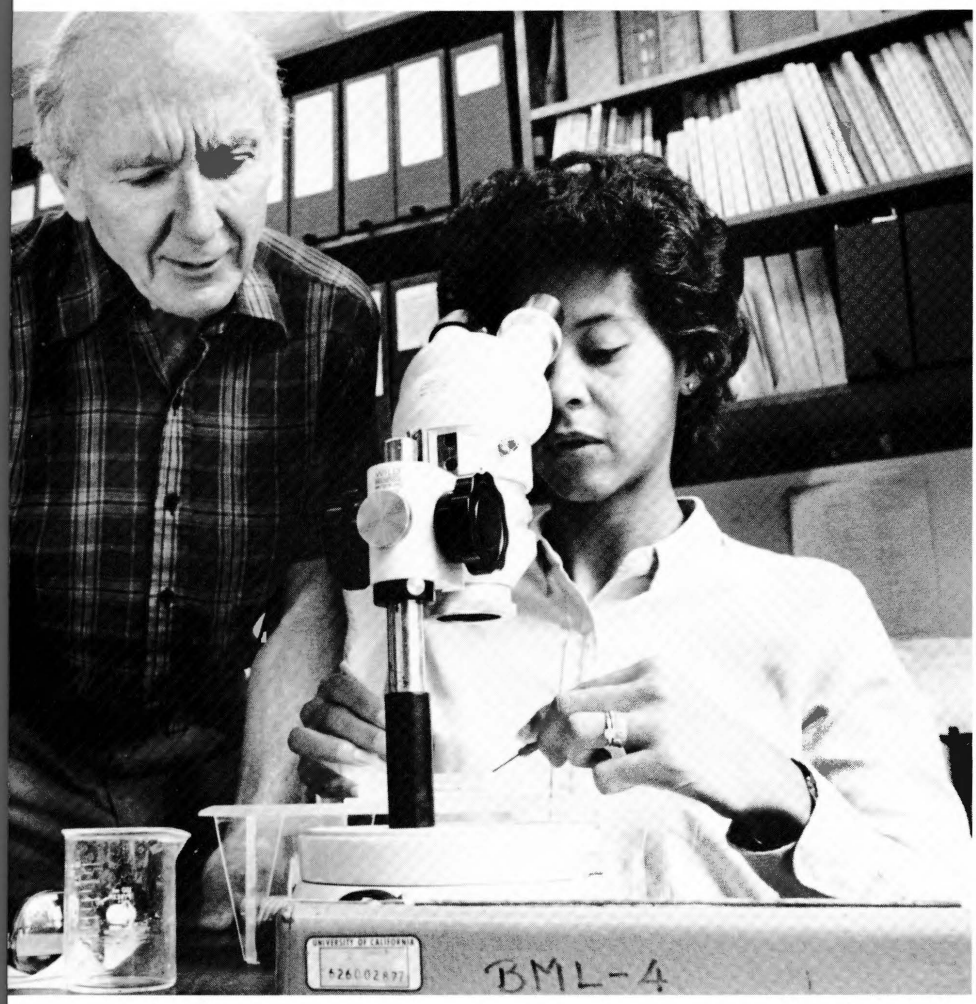
Scientists in Dr. Victor D. Vacquier's laboratory study the physiology of the sea urchin's sperm cell membrane. Of special interest are this membrane's proteins that mediate the activations of the sperm at fertilization. One protein is the enzyme guanylate cyclase, which is phosphorylated before the sperm contacts the egg; however, the instant contact is made, the protein dephosphorylates, and this decreases its activity 40-fold. This is the first nucleotide cyclizing enzyme shown to be regulated by phosphorylation. The phosphorylation of histone Hl also occurs when the sperm contacts the egg. The scientists identified a sperm membrane protein of 210,000 daltons that regulates ion fluxes in and out of the cell.

Dr. Benjamin E. Volcani's group continued their studies on silicon's regulation of gene expression and replication in diatoms. Dr. J. Richard Ludwig began analysis of gene banks from *Cylindrotheca fusiformis* containing specific silicon-responsive genes as cDNA clones and all of the genome as bacteriophage and cosmid clones. Extensive analysis was also carried out on diatom plasmid molecules, first discovered in this laboratory by graduate student Jerry D. Jacobs. Dr. Ludwig and a student have characterized the plasmids from *C. fusiformis* and have extended this analysis to numerous diatom genera and species. Dr. Ludwig is introducing these plasmids into bacterial cloning vectors to allow for a more comprehensive functional analysis. In addition, the incorporation of these plasmids into hybird cloning vectors will allow comparative analysis of plasmids from various diatoms by DNA-DNA hybridization, and the development of a system of diatom transformation. This, in turn, will allow for a functional analysis of the cloned diatom genes in the various banks described above.

Dr. Claude E. ZoBell continues to investigate the microbial synthesis and modification of surfactants. He is also directing research on the effects of submerged solid surfaces on the growth and metabolism of marine bacteria and related microorganisms.



Dr. Edward Brinton and Annie W. Townsend discuss the state of maturity of a specimen of Nyctiphanes simplex.



Marine Life Research Group

Work in the Marine Life Research Group proceeds in three major directions. The first is the accumulation and analysis of time-series observations of physical, chemical, and biological data on the California Current and adjacent water masses. The second is the study of cold-warm frontal systems, squirts, jets, and plumes via satellite-mediated shipboard observations. The third is observation of large-scale perturbation effects, such as the California El Niño of 1982-1984, and the return to normalcy following such events.

Time-series data were collected from approximately 600 stations in the California Current system during seven cruises aboard R/V *New Horizon*, and NOAA's research vessels *McArthur* and *David Starr Jordan*. Personnel from many U.S. and two Mexican institutions and several volunteers took part in these California Cooperative Oceanic Fisheries Investigations (CalCOFI) cruises. The data show that residual effects of the California El Niño event, which reached its peak in 1983, remained throughout 1984. However, the subsurface, high-temperature anomalies were less than half as large as the anomaly of +5°C observed at the peak of the warming in 1983. Strong coastal upwelling was observed in April 1984 between Monterey and Point Conception. The freshly upwelled water was characterized by very low dissolved oxygen levels (55 percent saturation) and very high nutrient levels. With the renewal of nutrients in the euphotic zone, primary productivity increased; by the May 1985 cruise, surface chlorophyll levels just south of Point Conception were more than 10 times those typically seen in the region, and the oxygen saturation was 149%. Data reports have been issued for all 1984 cruises and appear in the SIO Reference Series.

Dr. Edward Brinton is studying the population biology of euphausiid crustaceans in the California Current, comparing periods of warm and cold climate. During 1957-1959, 1977-1979, and the recent perturbation of 1982-1984, nearshore surface waters were 2°-4°C warmer than average. Particularly during the most recent warming, certain southern species replaced the usually dominant, cool-water species off southern and central California. *Nyctiphanes simplex*, like the pelagic red crab *Pleuroncodes planipes*, is usually found in and near Viscaino and Magdalena bays, Baja California, Mexico. During 1983-1984, *Nyctiphanes* established dense, persisting populations off southern California and Monterey Bay, even extending to the Pacific Northwest. Such events demonstrate that extreme environmental changes have occurred near shore. Species inhabiting the more offshore, main stream of the current system were less affected. Cool-water *Euphausia pacifica* retreated northward only 200-300 km, being replaced by southern species. Farther west, differences were less perceptible in the current, mirroring the negligible temperature differences there. Surprisingly, overall euphausiid biomass differed little, or

not at all, between warm and cold periods, although other zooplankters, less able to adjust their vertical positions in the ocean, were, like the phytoplankton, diminished during the height of the warm anomaly.

Dr. Thomas L. Hayward is studying the processes that regulate primary production and the population sizes of phytoplankton and zooplankton. Physical processes that affect the nutrients' supply rate to the euphotic zone from greater depths are important determinants of production. His examination of patterns observed during the 1984 CalCOFI cruises showed that primary production increased in the early part of the year and that macrozooplankton subsequently increased in biomass. This seasonal increase in production and biomass was associated with a shoaling of the nutricline, resulting in increased nutrient concentrations in the euphotic zone. This shoaling was, in turn, associated with increased transport to the south in the California Current and with coastal upwelling between San Francisco and Point Conception.

Drs. John A. McGowan and Elizabeth L. Venrick have investigated the roles of disturbance and perturbation in regulating the dominance structures and diversity of species within several trophic levels of the Central Gyre of the North Pacific Ocean and in the California Current. Environmental disturbances, on many scales, are important in many habitats. For instance, large-scale, aperiodic disturbances (such as fires or forest windstorms) provide conditions suitable to species (often called opportunistic species) that are not otherwise abundant. These disturbances facilitate the continued coexistence of more species than would be supported under undisturbed climax conditions. A consequence of the disturbance is that rare species become abundant.

Data for over 20 years from the central Pacific Gyre indicate extreme environmental stability. The fluctuations that do occur are insufficient to perturb the dominance structure: rare species remain rare. The ecosystem is resilient, apparently regulated to a large extent by biological interactions. By contrast, the California Current system is highly variable in both space and time, and its biology seems dominated by physical disturbances. The consequences of such disturbances, especially major ones such as the El Niño event of 1982-1984, are large variations in population sizes and in relative abundances. Thus the ecological interactions responsible for the resiliency and regulation of relative abundance (or stable dominance structure) of the gyre do not seem to have evolved in the California Current.

Dr. Mark R. Abbott is using satellite imagery of sea-surface temperature and near-surface phytoplankton pigment concentrations to study biological and physical processes in selected California Current regions. Phytoplankton patterns vary in both time and space in this region. These fluctuations result mainly from variations in processes like winds or mesoscale eddies. Analysis of a single upwelling event off northern California showed that phytoplankton abundances responded rapidly to changing wind conditions. Upwelling of nutrient-rich waters was localized between Cape Mendocino and Point Reyes, with the strongest upwelling near Cape Mendocino and Point Arena. Upwelling supported a large population of phytoplankton in the surface waters adjacent to these areas. The temporal and spatial patterns of wind forcing were primarily responsible for the observed phytoplankton variability.

The biology and chemistry of bottom sediments play an important role in the cycling of nutrients to and from the water column. Studies by Dr. Kenneth L. Smith and his colleagues focused on the energetics of deep-sea communities. Preliminary observations (from an oligotrophic station in the central Pacific and two eutrophic stations underlying the California Current off southern California) suggest that passively transported food energy is insufficient for the sediment community in most seasons.

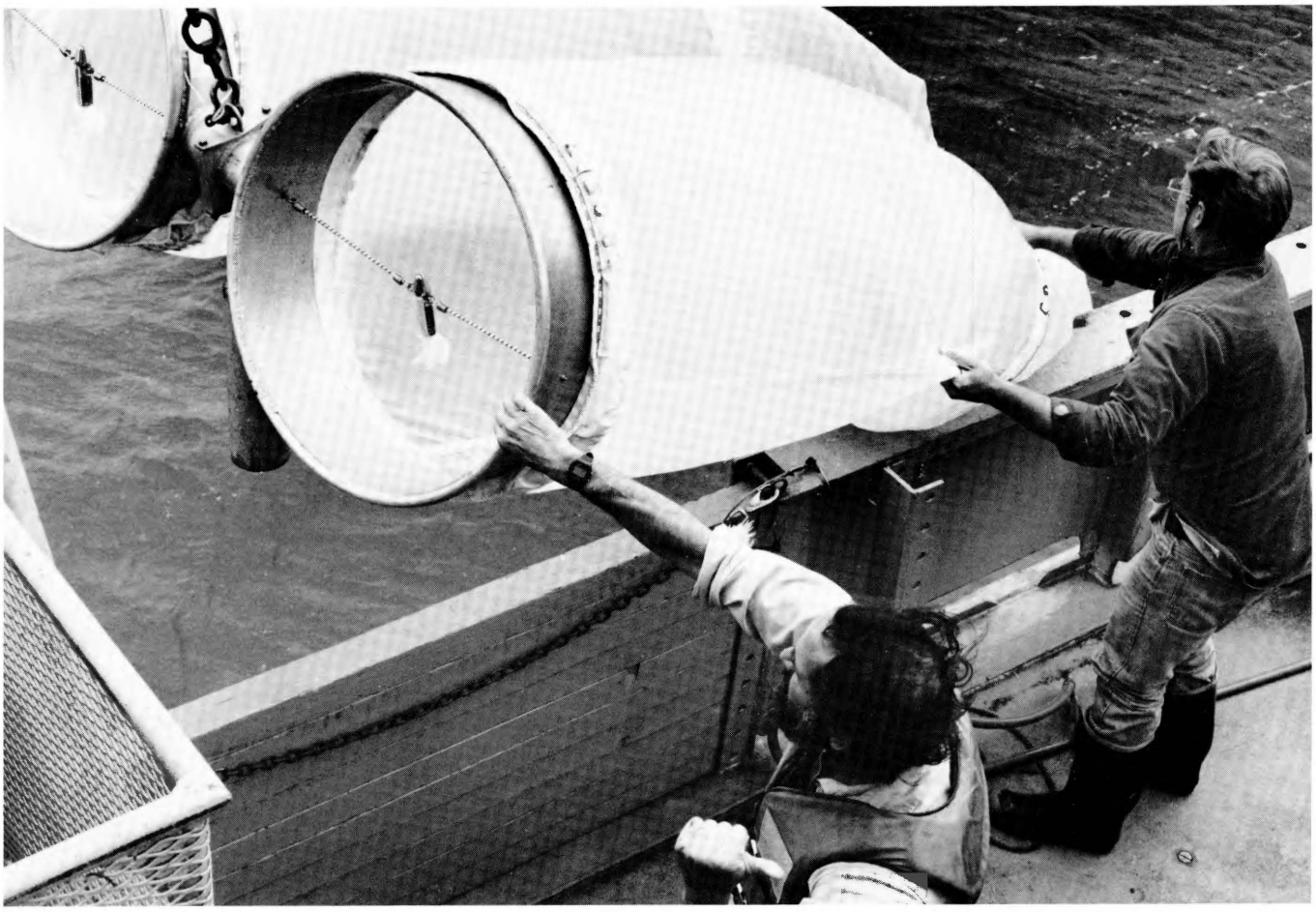
Dr. Dimitri Alexandrou is also examining this problem. He has deployed deep-free-vehicle acoustic arrays to quantify the actively transported food-energy supply. Graduate student W. Waldo Wakefield is evaluating the contribution of planktotrophic larvae of slope-dwelling species to the benthic food-energy transport. Graduate student Anastasios A. Tselepides is studying the sensory systems of deep-sea foraging fishes, and Raymond R. Wilson is studying decompression in grenadier fish.

Dr. Angelo F. Carlucci, Deborah B. Craven, and Dr. Richard A. Jahnke investigated sediment cores from the southern California borderlands for glutamic acid utilization, nucleic acid synthesis, and adenosine triphosphate (ATP) and bacterial biomass. They concluded that the southern California borderland is an area of high microheterotrophic activity, especially in the upper few centimeters of the sediments.

Dr. Abraham Fleminger examined sex determination in calanid copepods and presented a new hypothesis on sex change in these animals: the quadrithek dimorph appears to be the product of sex-change in the larger-sized late-juvenile potential male. The evolutionary and ecological significance of this hypothesis is that the larger-sized potential male, reaching adulthood one or more weeks before genotypic females, may increase its reproductive output.

Dr. James J. Simpson has observed that in situ concentrations of CO_2 and O_2 can depart radically from their expected oceanic equilibrium values, with respect to their atmospheric components, in areas of active upwelling, and that these disequilibria are caused by both physical and biological processes. Dominant time-scales are associated with biological processes. The global distribution of primary productivity, coupled with these and other small-scale and mesoscale measurements, suggests that coastal and polar regions may be in disequilibrium with respect to O_2-CO_2 exchange between ocean and atmosphere during parts of the year, and that equatorial regions may be in disequilibrium throughout the year. These observations place existing models of CO_2 transport in question.

Dr. Loren R. Haury and Robert C. Wilson retrieve bongo nets aboard R/V New Horizon. *The nets hold specimens of zooplankton and larval fish.*

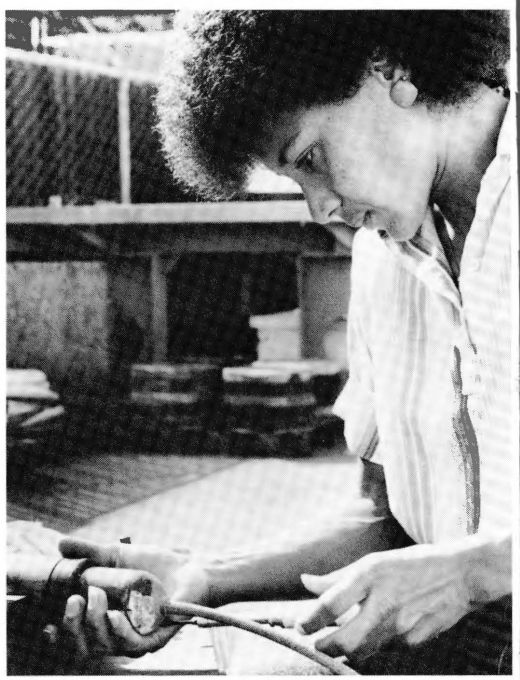


E. L. Venrick

Employing a free vehicle called the Cartesian Diver, Dr. Charles S. Cox and colleagues showed that velocity shear in the thermocline is dominated by inertial currents and is widely variable in intensity, and that severe episodes may be nonlinear. They observed naturally occurring fluctuations of pressure and electricity on the deep ocean floor. For periods shorter than 20 seconds, the fluctuations are associated with microseisms; for periods longer than 50 seconds, the pressure fluctuations are caused by long, sea-surface gravity waves, and the electric field fluctuations are caused by ionospheric disturbances. These observations are coherent over distances as great as 30 km.

Joseph L. Reid, in a study of the South Pacific Ocean, has prepared maps of the horizontal flow at all depths, from surface to bottom. Various tracers show the sources and paths of flow of the principal layers. These are the cold, dense, Antarctic Water along the bottom; the deep layer of high salinity from the North Atlantic; the mid-depth layer of low oxygen, high-silica water from the North Pacific; the layer of low-salinity water from the Antarctic; and the surface waters of local origin. Their patterns can provide references for vertical shear and thus define the geostrophic velocity field at all depths. In this model, water enters the South Pacific south of Australia at the rate of 135 million tons per second, while 5 million tons per second leave to the North Pacific, and 130 million tons per second pass below South America to the Atlantic.

Marine Physical Laboratory



Scientists at the Marine Physical Laboratory (MPL), under the direction of Dr. Kenneth M. Watson, are investigating underwater acoustics, marine physics and geophysics, signal processing, and ocean technology.

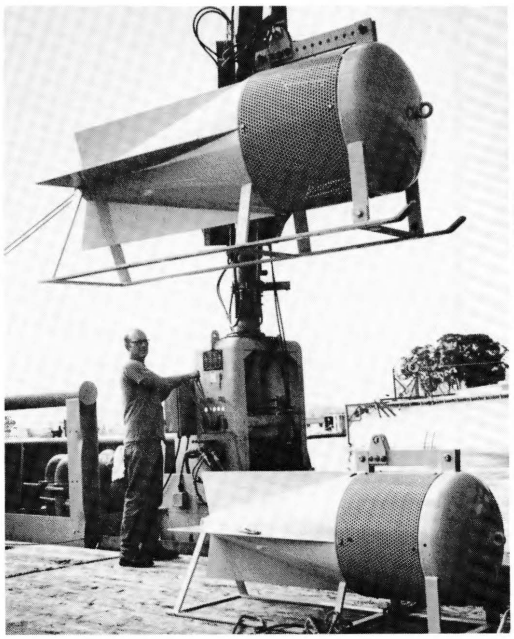
The Deep Tow group, directed by Dr. Fred N. Spiess, conducted the Rifts Expedition, leg 1, to obtain a fine-scale view, complemented by controlled sampling, of representative East Pacific Rise overlapping spreading centers. These features were previously documented with the swath mapping echo sounder system of R/V *Thomas Washington*. The expedition researchers chose to examine four centers located on the East Pacific Rise crest at 13°N, 9°N, 5½°N, and 4°N. Two of these are small features (~1km offset), and two are intermediate (3-5 km offset).

The Deep Tow system, transponder navigation, and controlled dredging all went well, with over 300 hours of towing (5 lowerings), 20 transponder launches and recoveries, and 25 successful dredge hauls. It is clear from preliminary inspection of the data (particularly side-looking sonar, precision sounder, and sediment profiler) that the overlap basins are essentially sediment free and differ from the nearby flanking zones in that the topography is dominated by constructional features rather than faulting.

In October, Dr. Peter F. Lonsdale led a diving expedition with Woods Hole Oceanographic Institution's submersible *Alvin*. A chain of volcanoes beneath 2,000-3,000 m of water, 300-800 km southwest of San Diego was the object of a geologic study of deep craters. The craters had previously been mapped on these seamounts with the Sea Beam echo sounder and the Deep Tow instrument. Rock samples were collected in stratigraphic sequences of lava flows exposed in the near-vertical crater walls, which are up to 500 m high. Visual observations helped clarify the sites and mechanisms of eruption and crater formation for this type of volcano.

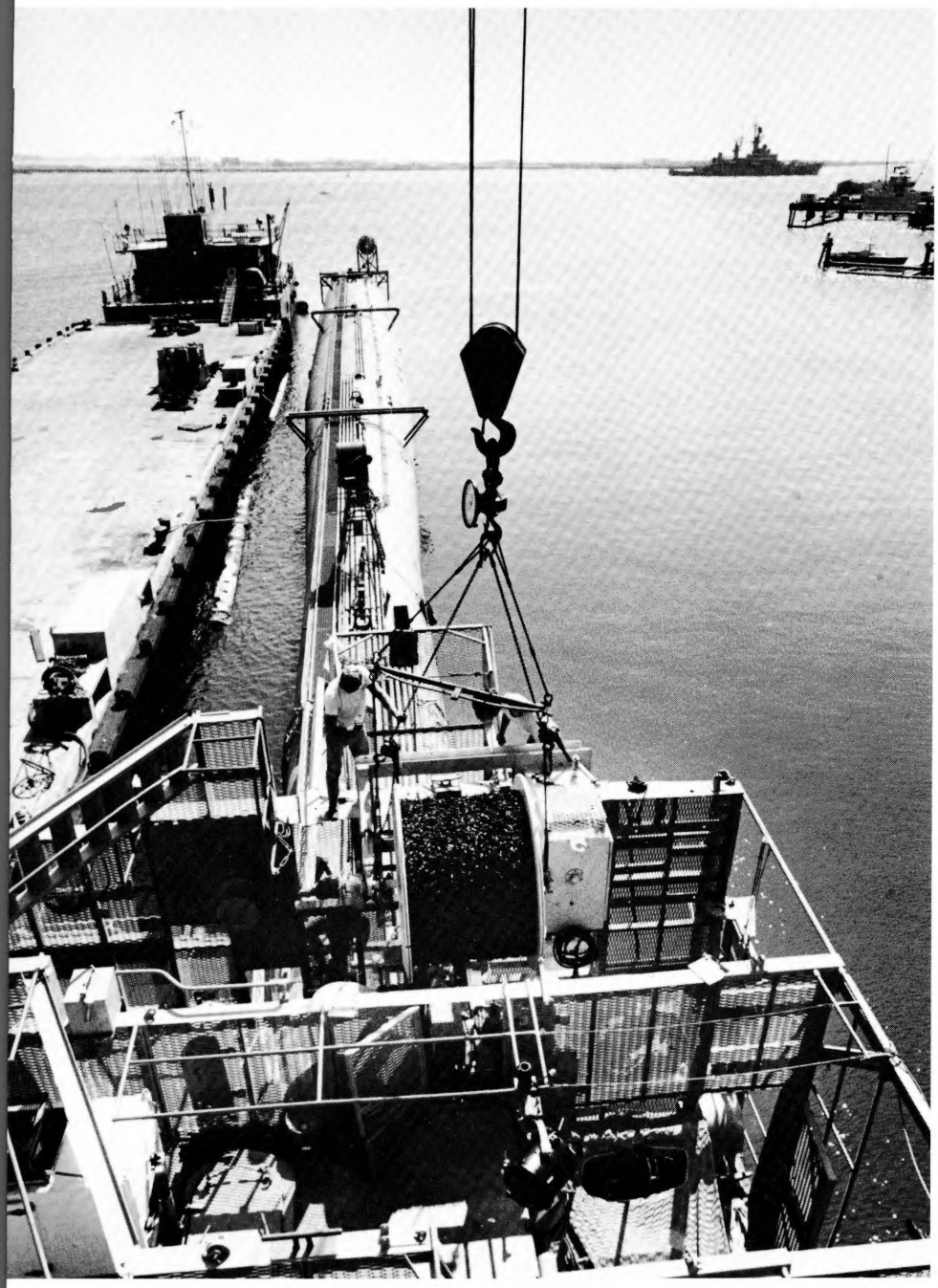
Dr. John A. Hildebrand is studying the internal structure of seamounts using two geophysical techniques: inversion of magnetic field anomalies, and inversion of ocean-bottom seismic waves. For the analysis of seamount magnetic anomalies, Dr. Hildebrand and Dr. Robert L. Parker are applying a general linear inverse theory, based on a Hilbert-space framework, to determine magnetic source characteristics. This method allows estimates of both the uniform and nonuniform components of the internal magnetization of seamounts. For the analysis of seamount seismic properties, Dr. Hildebrand is collaborating with Dr. LeRoy M. Dorman to develop a tomographic approach. They are placing ocean-bottom seismographs around the perimeter of a seamount to record the arrival time and the spectra of seismic waves resulting from a series of ocean-bottom explosive charges. Tomographic reconstruction allows mapping of the interior velocity and attenuation structure of a seamount.

Graduate student Christian P. de Moustier and F. Vince Pavlicek produce sidescan images by combining the acoustic returns received by Sea Beam's 16 individual beams. These images complement Sea Beam's standard high-resolution numerical bathymetry by providing seafloor textural information not available in the contoured bathymetry.



Dr. Robert Pinkel's upper ocean physics group studies the dynamics of small-scale motions in the top kilometer of the sea through data collection, data analysis, and instrument development. Data was collected at an ice camp in the Beaufort Sea in the Alaskan Arctic. Two 150 kHz Doppler sonar systems, profiled to depths greater than 300 m for nearly six weeks, showed that internal wave

Pamela L. Scott (upper left) dismantles a vertical array hydrophone after a cruise. . . . Terry G. Hoopes (lower left) lowers an HX-90 sound source in a tow body onboard the chartered Majestic Seahorse. . . . *Winch with faired cable (below) for vertical array is removed from R/P FLIP after a cruise.*



motions under the ice are significantly less energetic than in the open, mid-latitude ocean. Analysis of these Arctic data should provide an accurate estimate of the wavenumber-frequency spectrum of the internal wavefield, which can be compared with the form of more energetic mid-latitude spectra to indicate the nonlinear dynamical processes that govern the wavefield.

In the analysis of data sets obtained from FLIP off the California coast, Dr. Jerome A. Smith indicates that Doppler sonar, scattering at low angle from the underside of the sea surface, is a sensitive detector of low-frequency currents. He has detected patterns of sea-surface motion reminiscent of the so-called Langmuir circulation.

Dr. Frederick H. Fisher's research group conducted experiments at sea to study shallow-water propagation at low frequency (35 Hz), and deepwater ambient noise in the 100-400-Hz range. In shallow-water experiments, the resonant bubble gas bag sound source was used. The acoustic source level was about 170 db re 1μP ($\sim$1 watt) with an efficiency of about 5 percent. High ambient noise levels limited the range to about 10 km.

The digital vertical array designed by Dr. Robert B. Williams was used for the first time on a series of experiments around the Hawaiian Islands and between Honolulu and San Diego. This array, with integral cable and hydrophone assembly, is designed for low drag and is lightweight for easy deployment. Although the array appears fragile, it is easily deployed from FLIP to depths of 1,000 m in a few hours, and it did not develop any leaks or mechanical flaws in 12 deployments. The low drag of this array makes deployment possible without FLIP's usual three-point deepwater moor.

Both Dr. Fisher and Dr. Andrew G. Dickson are experimenting with electrical conductance at high pressure in electrolytes. They are interpreting results for LiCl solutions, focusing on selection of a theoretical conductance equation that gives reasonable results over a pressure range of 2,000 atm. The more modern Lee and Wheaton equation yields grossly unrealistic distance parameters at 2,000 atm, whereas the Fuoss-Hsia-Fernandez-Prini equation yields almost realistic ones. The objective is to provide uniform treatment of a wide variety of salts found at high pressures so that ion-speciation in seawater can be modeled as a function of temperature and pressure.

Dr. Dickson's solution chemistry group focuses on two areas: acid-base chemistry in seawater, and the chemistry of aqueous solutions at high temperature. Dr. Dickson made a highly accurate set of measurements of the dissociation constant of boric acid in seawater over a wide range of salinity (S = 5-45) and temperature (0-45°C).

The unmanned, deep-sea exploration vehicle RUM III (Remote Underwater Manipulator), designed and built by Dr. Victor C. Anderson and colleagues, can operate at 6,000 m. It is powered and controlled from a surface ship tethered by a 10,000-m coaxial strain cable. The first test of RUM III with the accumulator installed took place in 1,100 m of water using ORB (Ocean Research Buoy), which has a center well and winch for handling the vehicle. RUM operated successfully both above and on the bottom for 90 minutes.

Dr. William S. Hodgkiss, Jr., helped design and implement the system control and quick look/calibration analysis software for a high-speed data recording system for studying flow noise. Collaborative work with Dr. Anderson on the Swallow float array program continues. They are fabricating and testing at sea a freely drifting array for measuring infrasonic acoustic ambient ocean noise in the 1-20-Hz frequency region.

Dr. Daniel E. Andrews, Jr., is developing a flexible, reelable, cable-like motion-isolation module that can be interposed between a surface platform and a suspended instrument package. This module has sufficient compliance and damping to protect the submerged package from unwanted platform motion. The mechanism used in the new isolators combines strength members and a lossy elastomeric core so that longitudinal core stretching is accompanied by torsional shear, in a nonlinear manner that provides higher spring constant with increasing tension. Thus the module accommodates high shock loads without undue stretching or "bottoming out." Dr. Andrews and a student designed and assembled a machine for automatically grooving the elastomeric core used in the isolators.

Dr. Watson investigated the persistence of surface wave patterns. Observations, such as those of the SEASAT synthetic aperture radar, indicated that the wakes of ships may persist many kilometers astern. Several mechanisms (e.g., viscosity and direct wind interaction) destroy a pattern of waves like the Kelvin wake. In general, nonlinear interactions with the ambient sea appear to be more effective. Dr. Watson also studied the generation of internal waves by surface waves. The generation mechanism can be related to the formation of surface wave patterns by internal waves.

Dr. Henry D. I. Abarbanel continued studying the apparent dissipative behavior of a subsystem of a Hamiltonian system when the remainder of the full system is "integrated out." Using volume-preserving iterated maps to represent the Hamiltonian flows, Dr. Abarbanel and students came across a remarkable map on the four torus, which appears to have an infinite number of attractors in one of the subsets of the full four-dimensional phase space. Along with a visiting scientist, Dr. Abarbanel is investigating the nonlinear stability of three-dimensional inviscid fluid flows, which are either incompressible and homogeneous or barotropic—that is, the pressure depends only on the density. In each of these cases the conservation laws involve an additional conserved quantity beyond the familiar potential vorticity. Both conserved quantities are the result of the symmetry of the theory under relabeling the fluid particles while preserving density—a symmetry pointed out many years ago by Carl Eckart. In another study Dr. Abarbanel used an analogy between the behavior of a fluid in a rapidly rotating frame, such as the earth, and the motion of a charged particle in nonparallel strong electric and magnetic fields to construct a systematic Hamiltonian version of the familiar quasi-geostrophic expansion in Rossby number for shallow-water equations. From the analysis emerges an approximately conserved quantity analogous to the adiabatic invariants of plasma physics. With a student, Dr. Abarbanel is now investigating the numerical simulation of laboratory experiments on nearly geostrophic flow using this Lagrangian formulation. The numerical and analytic study of a several-layer model is also under way.

Neurobiology Unit

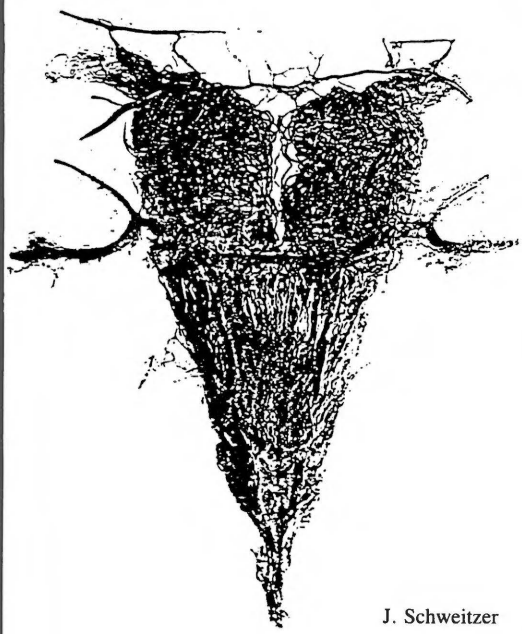
Scientists in the Neurobiology Unit (NU), associated with Marine Biology and the Marine Biomedical Program, study the sensory and neural mechanisms of natural behavior of sharks, rays, bony fishes, marine mammals, and other taxa. Because the brain is the most highly evolved system, and because its product, behavior, underlies ecological success, the approach of comparative neurology has been selected.

Dr. Theodore H. Bullock and a West German colleague are using computers to define differences in the brain's electrical activity in invertebrates such as *Aplysia*, the sea hare, and in vertebrates like the thornback ray. Dr. Jeff Schweitzer has characterized the midbrain responses to stimulation of electroreceptive sense organs in rays. Dr. Bullock and colleagues have begun to characterize the midbrain responses to lateral-line nerve stimulation in the same species. Another NU scientist mapped the responses to tactile and electroreceptor input in the cerebellar granule cell layer of the same species. All these studies use both electrophysiological evoked-potential recording and experimental anatomical methods for localizing the relevant centers.

Dr. Bullock and another colleague are recording from the hippocampus in reptiles in order to compare its dynamic properties with those previously studied in mammals.

A visiting scientist is comparing the central core gray matter of the brainstem, called reticular formation, in the classes of vertebrates, especially elasmobranchs. Other visiting researchers are working out an ethogram of two

Ocean Research Division



J. Schweitzer

A cast of a rete mirabilea (network of blood vessels) found over the brain of Mobula thurstoni, *a close relative of the manta ray, by Drs. Jeff Schweitzer and Giuseppe Notarbartolo-di-Sciara. This large tangle of arteries exceeds anything known inside the skull of any other vertebrate. The function of the rete mirabile is still a puzzle. The structure pictured is about 20 cm long, and comes from a ray weighing 10 kg.*

opisthobranch molluscs—the herbivorous *Aplysia* and the carnivorous *Navanax*. An ethogram is made by itemizing the repertoire of behavioral acts and the circumstances under which each is used.

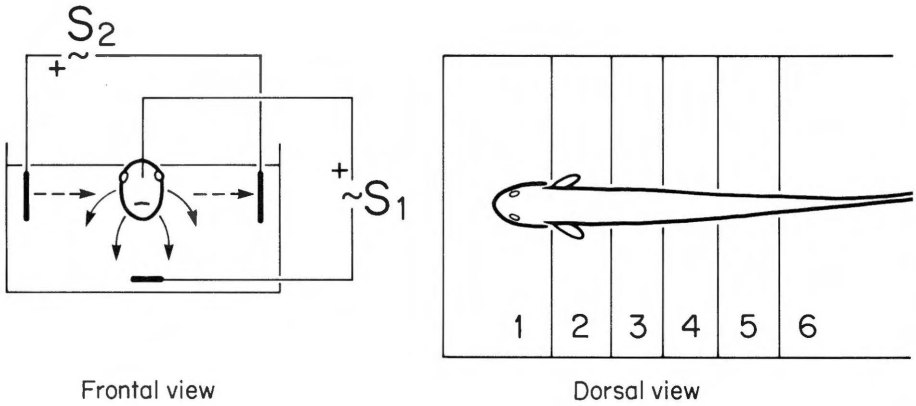
Ocean Research Division (ORD) researchers work in many scientific disciplines. Some aspects of their research are highlighted here: marine biology, marine chemistry, marine physics, and physical oceanography. Many other research programs are ongoing in ORD, but these few detailed descriptions will represent the whole. The Ocean Research Division also serves as the home of the Satellite Research Facility and the Physical and Chemical Oceanographic Data Facility (a branch of the Shipboard Support Technical Services Unit). Both facilities are described in the Facilities and Collections section of this report.

Marine Biology: Splitting Microseconds

Drs. Walter F. Heiligenberg and Gary J. Rose demonstrated through a variety of behavioral experiments that some electric fish species perform remarkable analyses of the temporal structure of electric signals. These animals produce an electric signal within a species-specific frequency range via an electric organ located in the tail. The fish detects these signals using electroreceptors, which are located throughout the body surface but are most highly concentrated in the head region. In the context of one electrosensory behavior, the Jamming Avoidance Response (JAR) of *Eigenmannia*, the fish determines whether a neighbor's electric organ discharge, which is jamming its own signal, is higher or lower in frequency than its own. The fish then decreases or increases its frequency accordingly. To determine the sign of the frequency difference, the fish detects the small-amplitude modulations, and modulations in the relative timing of signals received by different regions of its body surface (i.e., temporal disparity), which result from the addition of these two signals. At the threshold for this behavior, the fish senses a temporal disparity of approximately 400 nanoseconds.

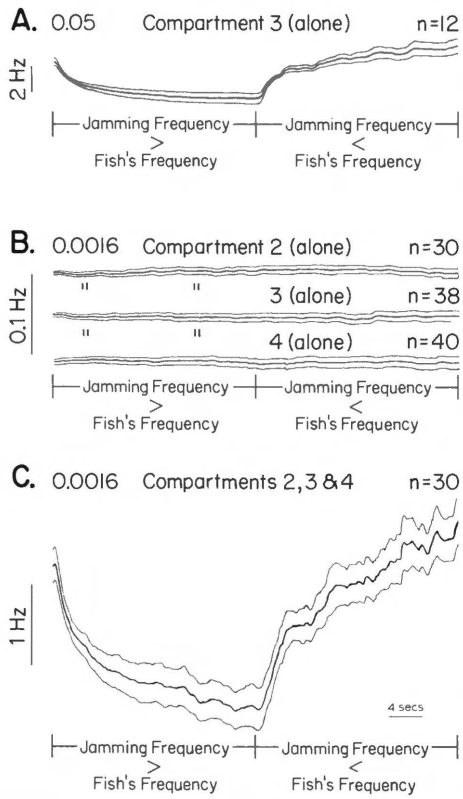
Is this remarkable temporal activity explained by high temporal resolution of individual receptor channels, or is this a case of hyperacuity; i.e., does it emerge in the central nervous system? Drs. Heiligenberg and Rose made electrophysiological measurements that indicate the phase-locked responses of the best receptor nerve fiber recorded are too jittery to permit such fine temporal resolution. This hyperacuity results from the nonlinear convergence, within the central nervous system, of parallel phase-coding channels from sufficiently large areas of the body surface. They studied the spatial convergence of sensory information by placing an immobilized fish into a multicompartment chamber. An electric signal (S1) mimicking the fish's own electric organ discharge (which had been silenced) and a jamming signal (S2) could be individually delivered to each compartment. Thus, with this arrangement, the body surface within each compartment could be stimulated independently.

The JARs, measured by recording the spinal command signal of the pacemaker, could be elicited from stimulation of the body surface within any of the individual compartments, provided the ratio between the amplitude of the jamming stimulus (S2) and



Frontal view

Dorsal view



Averaged jamming avoidance responses are shown. A signal (S1) replacing the fish's electric organ discharge, and a jamming signal (S2) that was alternately 4Hz higher or lower than the replacement signal were applied to individual compartments A, B or simultaneously to all three C. The ratio between these two signals, measured laterally to the fish's body, is given on the left-hand side of the figure. Center (darkest) trace is the mean, traces to either side indicate the standard error.

the amplitude of the replacement signal (S1) was sufficiently large. For example, an S2/S1 ratio of 0.05 produced a strong JAR when the stimulus was delivered exclusively to compartment 3. With this ratio the fish experiences a stimulus that has a maximum relative amplitude modulation of 5 percent and gives rise to a maxima/temporal disparity between the signal received by the left and right sides of the body of 28.4 microseconds. When the S2/S1 ratio was reduced to 0.00016, corresponding to a maxima/temporal disparity of 1.8 microseconds, no JAR could be observed upon stimulation of compartments 2, 3, or 4 individually; even after averaging 40 trials, a response could not be detected. Simultaneous stimulation of the body surface in these three compartments, however, elicited a strong JAR (inputs from these three individual regions of the body produced an unambiguous response).

Drs. Heiligenberg and Rose found that electroreceptive afferent inputs converge in a nonlinear manner to generate time disparity sensitivity of several hundred nanoseconds. In this process, inputs that are individually insufficient for eliciting a measurable JAR (even after averaging over two hours) produce a strong response when combined.

Marine Chemistry: Platinum Metals in the Ocean

Since 1960, chemists have developed the abilities to analyze smaller and smaller quantities of substances in seawater. In the 1960s assays for chemical species were made at the parts per million level and in the 1970s at the parts per billion level; today elements are successfully sought at the parts per trillion level. Drs. Edward D. Goldberg, Vernon F. Hodge, and Martha O. Stallard and Minoru Koide are studying the platinum metal concentrations in seawater, sediments, and organisms at these levels. For example, they found that iridium has a content in surface waters of 1 picogram per liter (one part per trillion), the lowest concentration of a stable element ever measured in ocean waters.

The six platinum metals (ruthenium, rhodium, palladium, osmium, iridium, and platinum) are the last group of elements in the periodic table to have escaped systematic study by marine scientists. However, their comparative chemistries may provide insights into oxidation-reduction and complexing reactions that will apply to other elements. For example, platinum is five times more abundant in seawater than is palladium, whereas their crustal rock concentrations are about equal. This is attributed to the greater ability of platinum to complex with chloride ions, and thus the element is less likely to be removed by biological or inorganic processes. Iridium has one-half the concentration of platinum in crustal rocks but one one-hundredth of its concentration in seawater. It is complexed much less than platinum or palladium. As a consequence, the residence time of platinum in ocean waters is about a million years, that of iridium about 40,000 years.

Both platinum and palladium have systematic chemistries in seawater. The distributions of platinum in three Pacific Ocean sites are similar to those of palladium, nickel, and such plant nutrients as phosphate and silicate, and emphasize the involvements of these elements in biological cycles of the sea.

Platinum and iridium are markedly enriched in manganese nodules over their crustal rock values. Some deep-sea rocks are in principle a platinum "ore" inasmuch as they contain up to a part per million of the metal. Such materials could be profitably mined if they were distributed on land. The nodules form in oxidizing environments where manganese and other elements in reduced states lose electrons to be placed in higher insoluble oxidation states. Dissolved oxygen gas is the oxidizing agent, i.e., electron acceptor. Palladium, which cannot be oxidized under normal conditions, is not enriched in these marine rocks, while platinum and iridium show parallel enrichments.

Mount Soledad Radiocarbon and Tritium Laboratory

Dr. Robert L. Michel of the Mount Soledad Radiocarbon and Tritium Laboratory studied the distributions of these two radioisotopes in the Antarctic region. The major sampling program was part of a multidisciplinary oceanographic study of the Southern Ocean off Wilkes Land between 147°E and 162°E. Previous data from this general area suggested that it might be a source region for deepwater formation. A shallow basin appears to exist on the continental shelf off Wilkes Land, where dense water could form. If dense waters exist in this depression, they could flow over the sill, mix with intermediate and deep waters of the Southern Ocean, and form a mixture that would sink to its appropriate density level. Previous cruises furnished very sparse data for the region, especially on the continental shelf and shelf break.

The recent cruise, aboard the U.S. Coast Guard cutter *Polar Star,* was designed to furnish an intensive survey of the physical and chemical oceanography of the region with emphasis on the shelf break. Most of the study area was ice covered. Seven sections of closely spaced hydrographic stations were obtained perpendicular to the shelf break in the potential formation region. Complete profiles of temperature, salinity, and oxygen were made at all stations using a CTD and oxygen sensor. At selected stations, samples for chemical tracers were also collected to augment the physical data. The transient tracers are extremely useful in the study of freshly formed bottom and deep waters. Samples for tritium were collected and drawn into one-gallon bottles and returned to the Mount Soledad Laboratory for analyses. Freons were sampled at selected stations on most sections and in the atmosphere. They were collected and analyzed on board by Frederick A. Van Woy. Dr. Robin S. Keir, in charge of the alkalinity and carbon dioxide program, carried out onboard analyses of pH and alkalinity. Carbon-14 samples, collected by extraction of the dissolved inorganic carbon (DIC) from 120 liters of seawater, were gathered from all major water masses and returned to the Mount Soledad Laboratory for analyses. The preliminary results of the program indicate no markedly anomalous mid-depth water was present during the 1984-1985 Austral summer. However, it does appear that freshly formed bottom water was present at that time.

Data from the Scotia and Weddell seas obtained during a multidisciplinary study of the area in 1981, is still being analyzed. A carbon-14 gradient in surface water DIC across the Weddell-Scotia confluence with lowest concentrations occurring in the Weddell Sea was found. From this data and previous Weddell Sea measurements, scientists were able to model the carbon-14 concentrations in surface (DIC) for the Weddell Sea during the bomb transient. They estimate the prebomb Weddell Sea to have a $\Delta^{14}C = -144$ o/oo. The carbon-14 levels would start to rise with the advent of nuclear testing and reach a peak in 1965-1967. The peak concentrations would vary between −70o/oo to −80o/oo, depending on the uptake rate of atmospheric carbon-14.

Physical Oceanography: Volunteer Observing Ship Program

The Volunteer Observing Ship (VOS) Program, under the direction of Drs. David L. Cutchin and Warren B. White, arranges for oceanographic and atmospheric observations from volunteer "ships of opportunity." Most of the vessels now enrolled in the VOS program are containerships and tankers that regularly cross the Pacific. The VOS Program is a cost-effective approach to the collection of large data sets that span long time periods and wide ocean areas. Scripps's VOS Program is operated in close cooperation with similar national and international programs.

During the past two years graduate student J. Justin Lancaster and Dr. Charles D. Keeling have used vacuum flask air samples collected onboard containership *Paralla* to help establish the seasonal, latitudinal, and longitudinal variability of atmospheric CO_2 concentrations over the North Pacific.

Dr. Cutchin completed the installation and testing of an acoustic Doppler current profiler (ADCP) on the *EXXON Jamestown*, which makes monthly round trips between Houston, Texas, and Santa Barbara, California, via the Panama Canal. The *EXXON Jamestown* project involves the first use of Doppler profiling onboard a commercial ship. The ADCP operates almost automatically; only occasional tending is needed.

Most of the VOS Program is devoted to using XBTs to observe changes in the thermal structure of the North Pacific and tropical Pacific. Scripps's Pacific XBT data base, collected by volunteer ships over a ten-year period, has been used by over fifty scientists from twenty-six research institutions and government laboratories in the U.S. and seven other countries. Scripps researchers are now using the data to study the effects of bathymetry on the thermal structure, to follow the generation of baroclinic Rossby waves, and to investigate heat transport and storage in the upper ocean.

Interest in the Pacific Ocean temperatures is centered around El Niño. Drs. Warren B. White and Stephen E. Pazan developed what may be a method of using XBT data to forecast the occurrence of El Niño in advance. The historical data indicate that anomalous wind conditions occasionally build up an unusually thick surface layer of warm water in the vast ocean area to the southwest of Hawaii and north of the equator. A lenslike warm-water feature occurred in the area during November-December 1981. A long time series of similar maps shows that when the winds release the lens, it propagates slowly westward at the theoretically determined velocity of baroclinic Rossby waves. Drs. White and Pazan determined that, historically, when this type of lens reaches the western edge of the tropical Pacific in the Northern Hemisphere winter, El Niño follows. The lens moved westward in early 1982, and a very strong El Niño began in mid-1982. The physical connections between the motion of the warm-water lens and the initiation of El Niño are under investigation. Although the warm-water lens is adequately defined by the available data, there are large gaps in the area of the lens. In order to help fill these data gaps, two new volunteer ships were instrumented and are now taking XBT data.

VOS Program is a prime example of successful cooperation between private industry, government, and academic research institutions. Efforts are under way to cover more ocean areas and to collect different types of oceanographic and meteorological observations.

Dr. Lynne D. Talley examines new charts of geostrophic ocean velocities in search of previously unknown features.

Transpacific Profiles

Work carried out in the laboratories of Drs. Dean H. Roemmich, James H. Swift, and Lynne D. Talley included a transpacific expedition aboard the University of Washington's R/V *Thomas G. Thompson*. The principal objectives were the elucidation of the general circulation of the North Pacific, estimation of the heat transport by ocean currents in the North Pacific, and measurement of tracer distributions.

Two hundred and sixteen stations were made with a conductivity-temperature-depth (CTD) profiling instrument that was lowered to the ocean bottom. The CTD was attached to a frame that also carried 36 10-liter Niskin bottles. During the transect, more than 6,500 water samples were collected from the bottles for analyses of salinity, dissolved oxygen, and nutrients. The Physical and Chemical Oceanographic Data Facility carried out the data collection.

This CTD/hydrographic section, nominally along latitude 24°30′N, was the most heavily sampled transoceanic section ever carried out. It was the first ever to make use of a 36-bottle rosette designed by Paul R. Sweet. Finally, with the new computer system, it was the first CTD cruise of its magnitude during which data processing kept up with data acquisition so that scientific analyses could begin immediately after the cruise.

A number of ancillary projects accompanied the main CTD/hydrographic work. Because of the large number and volume of water samples, it was possible to measure freons, trace elements, chlorophyll-*a* and primary productivity, tritium/helium-3, and phytoplankton pigments. Finally, measurements of current shear to 1,500 m were made at 200 stations.

Marine Physics

Drs. Charles S. Cox, Steven C. Constable, Alan D. Chave, and Spahr C. Webb carried out a dipole-dipole electromagnetic sounding in the North Pacific during 1984. They used a transmitter and several receivers located on the seafloor. The experiment was performed on crust of 25my age (magnetic anomaly 6E) having thin sediment cover. Electromagnetic signals in the frequency range of 0.06 to 24 Hz were injected into the ocean and seabed by a horizontal electric dipole antenna dragged by ship along the seafloor. The electric fields that propagated through the resistive basement were detected by receivers at ranges of 10 to 65 km. Although weak, these signals were measurable because the ambient seafloor electric field is very small.

The propagation of electromagnetic signals at the transmitted frequencies in conducting seawater and rocks is essentially a diffusive process, because the conduction current far exceeds the displacement current. The attenuation with range of an electromagnetic disturbance increases with the conductivity of the medium, and is very rapid in seawater. The detection source at the long distances used in this experiment implies propagation through the rocks below the ocean floor. The variation of the electric field amplitude range and frequency provides information on the subseafloor electrical conductivity as a function of depth.

Models of layered structures that adequately fit the data were constructed by trial and error. The best (in a least-squares sense) two-layer model consists of an upper layer of 4.5 km thickness and moderate (.0011 S/m) conductivity, presumably representing cool, fractured, and water-saturated crust. (The units of Siemens/meter are equivalent to reciprocal ohm meters.) This is underlain by a halfspace of low conductivity (2×10^{-5} S/m). A variety of models featuring an increase in conductivity at depth in the mantle fit the data equally well. A model characteristic is that as the deep conductive zone is made shallower, the conductivity of the resistive zone must decrease.

The two sets of laboratory data represent fertile and completely depleted models of mantle conductivity in the sense that partial melting of garnet lherzolite yields basalt, while the pure olivine of peridotite cannot. Both models show the conductivity increase associated with the increase of temperature with depth in the mantle.

The laboratory measurements on which these models are based were made on completely dry rocks. If water is present, the conductivity in the comparatively cool parts of the uppermost mantle will be greatly increased by the mobility of ions in the intergranular fluid and in absorbed films on the grain boundaries.

Our measurements allow us to place a rough upper limit on the volume fraction of water present in the upper mantle. The minimum conductivity (10^{-5}S/m) between 5 and 30 km below the seafloor implies an upper limit of about 10^{-3} for the average volume fraction of water in this region. This surprisingly small value implies that very little if any seawater penetrates the upper mantle, and juvenile water, if originally present in the mantle, has been largely swept out during the process of seafloor creation at a spreading ridge.

Physiological Research Laboratory

The physiological and biochemical adaptations of aquatic and terrestrial animals are the focus of Physiological Research Laboratory (PRL) scientists. Dr. Fred N. White completed his studies of diving turtles. He investigated their lung gas composition and blood-flow patterns during diving. When a turtle is submerged, oxygen is depleted from the lung at a steady rate, while only a small fraction of the carbon dioxide produced by metabolism enters the lung. This gas exchange pattern is attributable to alterations in the chemical binding characteristics of the two gases in pulmonary blood. Hemoglobin takes up oxygen more easily, and carbon dioxide is released more slowly as breathholding proceeds. Blood flow to the lungs diminishes because of a partial bypass of blood from the tissues within the incompletely divided heart. Thus a portion of the carbon dioxide entering blood at the tissue level recirculates to the tissues where it was stored.

This selective storage of carbon dioxide in tissues produces acidification—a trend that reduces hemoglobin's capacity to bind oxygen. The result is improved oxygen release at the tissue level. At the lung, the low efflux of carbon dioxide minimizes acidification of the blood. The results are preservation of the oxygen-binding characteristics of the hemoglobin traversing the lung, and depletion of the oxygen stores in the lung to low partial pressures. These patterns of shifting blood flow and blood-gas transport are responsible for extending aerobic diving time.

Dr. Jeffrey B. Graham and graduate student Daniel C. Abel are studying the pericardioperitoneal canal in sharks and rays. They have learned that shark pericardial pressures need not always be negative to ensure normal cardiac function. In collaboration with Canadian and Panamanian colleagues, Dr. Graham continued studies of the sea snake *Pelamis platurus*, using the Hydraulic Laboratory's 10-m-deep tank to examine the snake's feeding behavior, subsurface swimming pattern, and buoyancy control. The respiratory physiology of the swamp eel *Synbranchus* was also studied in Dr. Graham's laboratory. This fish can take up sodium from water using its skin, and its air-breathing organ has both gas volume and oxygen content sensors that regulate its heart rate.

Scientists in Dr. Edvard E. Hemmingsen's laboratory are investigating the mechanisms of bubble nucleation during decompression of cells and organisms. They want to identify factors that promote the bubble formation *in vivo* at relatively small degrees of gas supersaturation and that may contribute to (or cause) decompression sickness in divers. Whereas it is generally assumed that microscopic gas nuclei chronically exist in organisms and cause the bubbles, these investigations indicate that bubbles may form spontaneously rather than from preformed nuclei.

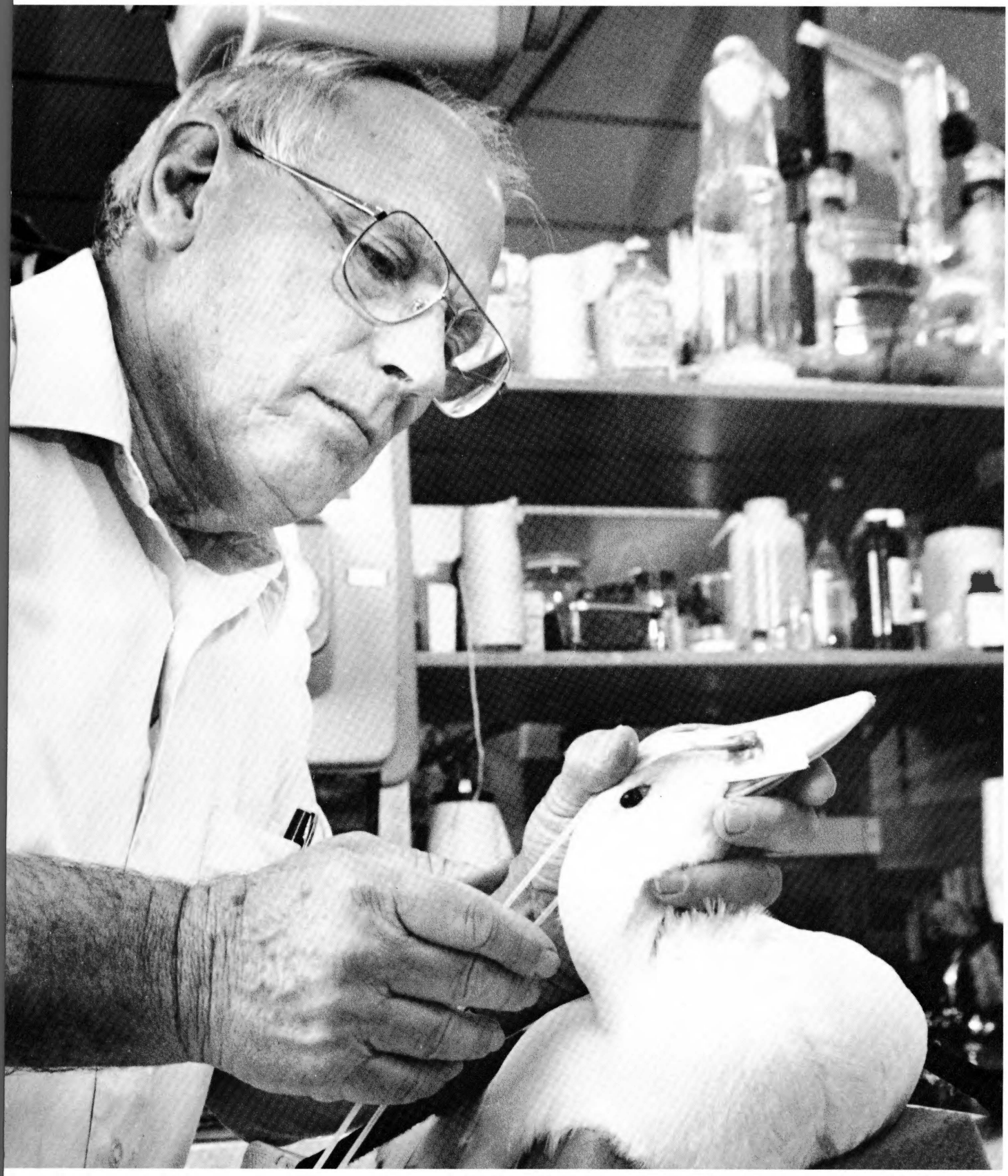
Physiological and behavioral adaptations to swimming and diving in aquatic vertebrates continue to be the focus of Dr. Gerald L. Kooyman and collaborators. Dr. Steven D. Feldkamp completed a study on hydrodynamics and behavior of the California sea lion. Female sea lions, foraging between visits to shore to nurse pups, made several hundred dives during the 2.5-day trips to sea. While at sea they spent only 3 percent of their time resting. However, during this time, their metabolic rates, if close to the preferred swim rates measured in captive animals, would be only about 2 to 3 times the resting rates.

Dr. Martha E. Heath is studying diverse aspects of body-temperature control in vertebrates. She has demonstrated that the rate of heat transfer between a mammal's body and the environment is strongly dependent on the red blood cell concentration (hematocrit) of the blood. Reductions in hematocrit sharply reduce heat loss from the body. Dr. Heath also investigated the neural control of body temperature, and found evidence for extrahypothalamic sites of temperature sensitivity in the brain.

Dr. A. Aristides Yayanos and his colleagues are studying the biochemical adaptations that permit animals and bacteria to thrive at extremes of hydrostatic pressure. Graduate student Edward F. DeLong discovered that deep-sea bacteria are capable of adjusting the lipid compositions of their membranes during growth at different pressures. These lipid adaptations are thought to confer stability of membrane function under extremes of pressure, and they may allow these deep-sea bacteria to acclimatize to life at different depths. Deep-sea amphipods are being raised at in situ temperatures and pressures. Scientists in Dr. Yayanos's laboratory are also interested in the effects of radiation in the deep sea. Graduate student Linda H. Lutz is examining how DNA repair systems, which often correct errors in DNA structure induced by radiation damage, differ between deep-sea and shallow-living bacteria.

Dr. Harold T. Hammel and James E. Maggert continued their studies of salt secretion in marine birds. The salt gland clears excess salt by increasing the salt content of extracellular fluids. Regulation of salt gland activity also involves neuromodulation by the excretory center in the supraoptic nuclei of the brain. This control center continues to regulate salt gland activity even after the original stimulus for activity—an increase in extracellular fluid concentration—has disappeared.

Dr. Harold T. Hammel tapes over a Pekin duck's external nares with tubing that aspirates excretions from the salt glands. By comparing the rate of salt excretion with the rate of salt infusion into the bloodstream, he studies the process by which marine birds eliminate excess salt.



California Space Institute

The California Space Institute (Cal Space) is a multicampus research unit of the University of California that supports and participates in space-related research. Cal Space, under the direction of Dr. James R. Arnold, is headquartered at Scripps.

One of the major multicampus activities of Cal Space is the minigrant program that provides seed money for UC investigators in astrophysics and planetary sciences, remote sensing, climate, and material processing in space.

Several large projects have been developed by Cal Space at Scripps, including participation in the multi-investigator study of the tropical Pacific (Tropic Heat). This study is aimed at elucidating the physical processes that determine the upper-ocean distributions of temperature and velocity in the central and eastern equatorial Pacific. Dr. Catherine H. Gautier is studying the air-sea interactions taking place in this same area.

Cal Space directed a panel on automation and robotics. The National Aeronautics and Space Administration (NASA) and the U.S. Senate requested the panel's formation. They wanted an independent assessment of potential advances in automation and robotics, believing such advances could increase the space station's capabilities and economic effectiveness. The final report was delivered to NASA.

Cal Space also directed a summer study entitled "Technological Springboard to the 21st Century." An interdisciplinary group of faculty and fellows investigated space development, material technologies, space-based propulsion and energy generation, and economic modeling. Results are being compiled at the Johnson Space Center.

Cal Space has increased its in-house research activities in two areas: remote sensing of the ocean-atmosphere system and space industrialization. In the latter area, Dr. Arnold is directing studies connected with NASA's planned space station, particularly on technologies that can make it a lower-cost, more flexible system for a wide range of applications. A second theme is materials processing in space, extending from applications in near-earth orbit to the use of lunar resources for propellants and in connection with the establishment of a lunar base.

Dr. Robert L. Parker with computer models of the magnetic field around submarine volcanoes.

Institute of Geophysics and Planetary Physics

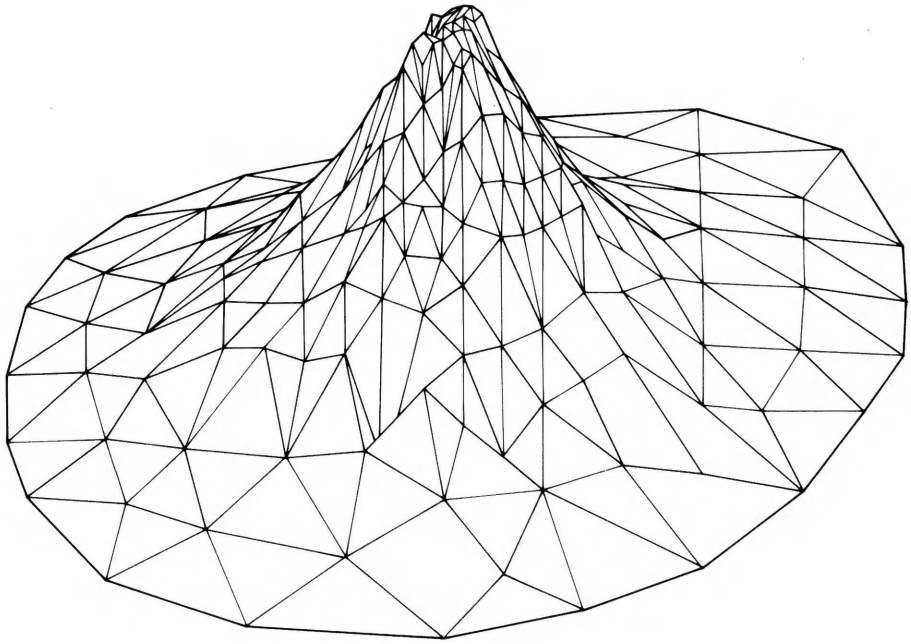
The San Diego branch of the University of California systemwide Institute of Geophysics and Planetary Physics (IGPP) is located at Scripps Institution, and is strongly linked to Scripps through joint faculty appointments, research interests, and shared facilities. Other IGPP branches are located at the Los Angeles and Riverside campuses and at the Los Alamos and Lawrence Livermore national laboratories.

Dr. George E. Backus and graduate student Susan E. Hough found that magnetic signals with periods shorter than 10 years need not emerge through the mantle from the core to explain the European records of the 1969 magnetic jerk. The same conclusion for worldwide signals was reached with colleagues from the National Aeronautics and Space Administration. Work with a French institution showed that at the top of the core, geostrophy permits unique determination of the core-fluid velocity from surface measurements of the time-dependence of the geomagnetic field B, except in an ambiguous patch around each null-flux curve (curve on the core-mantle boundary where the radial component of B vanishes).

Dr. Duncan C. Agnew studied ocean tide and crustal deformation measurements, and began work on noise sources in very-long-period seismic measurements. Preliminary results indicate that tilts caused by pressure-related flexure of seismic vaults may be a major noise source.

Frank K. Wyatt III and Dr. Agnew direct work at the Cecil and Ida Green Piñon Flat Observatory, a field station in the Santa Rosa Mountains for the development and testing of instruments to measure crustal deformation. Recent results from a long-base tiltmeter show very low drift (40 nrad/yr) and noise, with a slight apparent correlation with barometric pressure. The researchers have also used a fiber-optics system to measure the stability of the reference standards used in the laser strainmeters.

A mathematical model representing Stoddard Seamount by triangular facets used in the inversion of magnetic observations.



Dr. Agnew continued to direct the Project IDA global network of 18 very-long-period seismometers. Network data are sent to several other institutions and are used for studies of earthquake mechanisms and earth structure.

Dr. Michael S. Reichle of the California Department of Conservation's Division of Mines and Geology, and Drs. James N. Brune and John G. Anderson continue cooperative seismic studies with Mexico. Their studies encompass seismic hazard, earthquake strong motion, earthquake mechanism, and earth structure. Observations and theoretical, numerical, and physical models were combined to predict probabilities of large ground accelerations that might cause structural damage.

Drs. Anderson and Brune are directing the Mexican installation of a strong motion accelerograph array, which consists of 29 digital recording accelerographs. These are installed in the seismic gap that last ruptured in a four-earthquake sequence between 1899 and 1911.

As part of a U.S.-Mexican study of crust and mantle structure along the cordillera of western North America, three long-period seismograph stations are being operated in Mexico by IGPP scientists and colleagues.

Dr. Anderson and Hough continued their study on the effect of attenuation on the Fourier amplitude spectrum of high-frequency acceleration. Dr. Anderson and a colleague began studying the effects of incoherence in earthquake ground motions on structures' response to earthquakes. They also continued investigating the recording pier's effect on records of strong earthquake ground motion.

Drs. Brune and Ralph H. Lovberg are designing polyurethane models to study strong ground motion during earthquakes. Vibrations are studied using optical transducers.

Linear inverse theory is used by Drs. Allen H. Olson and Brune to determine the behavior of earthquake faulting. The need for an accurate Green's function poses serious limitations on this methodology, because theoretical ground motions can only be computed for simple geologic structures. The scientists are estimating Green's function from a catalog of digitally recorded aftershocks in an effort to extend understanding of faulting and the resulting ground motions to higher frequencies and long distances.

Dr. Alan D. Chave investigated the nature and applications of electromagnetic fields in the ocean. Dr. Chave and a colleague implemented robust time series analysis methods designed to remove the contaminating effects of magnetic storms from electromagnetic data taken at the seafloor. With another colleague, he completed a study of transient electromagnetic prospecting for seafloor sulfide mineral deposits.

Dr. John W. Miles continued his work on nonlinear waves and chaotic motion in dynamical systems.

Drs. Walter H. Munk, Peter F. Worcester, Robert A. Knox, and Bruce D. Cornuelle and a graduate student focused on ocean acoustic tomography (the indirect measurement of ocean density structure and currents), observing the travel times of acoustic pulses propagating through a specific ocean region on several different paths. A recent experiment demonstrated that tomographic measurements of currents over 300-km ranges can be made. Analysis of resulting data led to an understanding of how to reduce errors inherent in the technique. Considerable refinement of the computational methods for working from observables (travel times) to desired results (density structure) resulted from analysis of the 1981 experiment.

Dr. John A. Orcutt and graduate student Thomas J. Sereno, Jr., described the excitation and propagation of several enigmatic oceanic seismic wave trains generally termed PN, SN, and T phases. These waves are characterized by very-high-frequency propagation over ranges greater than 4,000 km, and by a very slow decay in time within observed seismograms. The model adopted consists of a typical oceanic crustal structure overlying a nearly homogeneous uppermost mantle or lithosphere. Synthetic wave trains were computed at IGPP, and the resultant seismograms matched the observations even in detail. By analyzing South Pacific data, Dr. Orcutt and graduate student Peter M. Shearer discovered that the upper crustal and uppermost mantle velocities varied as a function of azimuth. That variation in velocity was correlated with a proposed crustal lithology based on the study of ophiolite suites (collections of rocks currently lodged on continents), which are believed to have been oceanic crust in the ancient earth. Graduate student Mark S. Burnett and

Dr. Orcutt used East Pacific Rise seismic data to constrain the magnitude of a crustal magma pool, which supplies the axial volcanoes responsible for the forming of most of the earth's crust. Burnett and graduate student Isaac I. Kimm accompanied Dr. Orcutt on an extensive, two-ship, seismic survey of the East Pacific Rise axis north of the equator to delimit the along-strike and lateral variations in this extensive magma body. Dr. Orcutt and graduate student Kenneth M. Toy are studying the propagation of seismic waves through the earth in order to develop a three-dimensional view of the entire earth using techniques similar to those used in medical tomography. Dr. Orcutt and a graduate student used data from the Southwest Pacific to develop a comprehensive theory for the excitation and propagation of seafloor and continental seismic noise.

The internal magnetic structure of seamounts has been a long-term interest of Dr. Robert L. Parker. Observations of the magnetic field around these submarine volcanoes do not provide enough information to determine the exact magnetization within, but it is possible to discover important properties. With Dr. John A. Hildebrand, Dr. Parker developed a method of calculating the simplest magnetization consistent with the magnetic data, where "simplicity" is defined as slight deviation from a completely uniform state. There is reason to believe the true magnetization is not far from this simplest state; thus the model structures are thought to be closely related to the true magnetization.

Dr. Richard L. Salmon is developing numerical models for large-scale density structure in the ocean. The model equations, which are obtained by approximation methods based on Hamiltonian mechanics, are simple enough to be solved efficiently, but maintain exact conservation laws.

Bernard D. Zetler continued his ocean-tide research. With Dr. Reinhard E. Flick, he extended a study of predicted extreme high tides for California to a generalization of criteria for predicted extreme heights for mixed-tide regimes.

The Institute of Marine Resources

The universitywide Institute of Marine Resources (IMR), directed by Dr. Fred N. Spiess, is headquartered at Scripps. As part of its intercampus activities IMR conducts workshops and seminars on specialized topics, and supports graduate students in ocean-oriented fields who wish to study temporarily on a UC campus other than their own.

Marine Natural Products Group

The Marine Natural Products Group focuses on biologically relevant natural products produced by marine plants and animals. Under the guidance of Dr. William H. Fenical, the group investigates the defensive chemical adaptations of tropical marine plants and gorgonian corals. In addition, the group has expanded its activities in marine pharmacology.

Graduate students Valerie Jean Paul and Niels L. Lindquist studied the chemical ecology of tropical green algae and ascidians. They found that a major adaptation against predation is the evolution of toxic and noxious metabolites.

Graduate students M. Sofia Gil-Turnes and Jongheon Shin are studying the chemical adaptations of marine bacteria and fungi, with particular emphasis on the symbiotic relationships these microorganisms maintain with plant and invertebrate hosts.

The chemistry of gorgonian coral *Pseudopterogorgia* has continued to capture the interest of graduate student Mark T. Burch. His work has both ecological and biomedical implications, and he has spent considerable time developing a chemotaxonomy scheme for species-level taxonomic assignments within this genus.

Dr. Kirk R. Gustafson's work in chemical marine microbiology led him to a collaborative university-industry program to explore the biomedical potential of this undeveloped resource. Dr. Amiram Groweiss studies the unusual metabolites produced by Pacific soft corals and gorgonian corals.

Food Chain Research Group

The Food Chain Research Group (FCRG) is led by nine principal investigators. Dr. Farooq Azam and coworkers are studying the role of bacterioplankton in the flux of matter and energy in pelagic marine food webs. They find that the secondary production of heterotrophic bacterioplankton consumes about one-half of the primary production. Their research focuses on the physiological and biochemical adaptations that allow bacterioplankton to effectively use dissolved and particulate organic matter in the pelagic ocean.

Dr. James W. Ammerman is exploring the importance of marine bdellovibrios, small predatory bacteria, as consumers of bacterioplankton. Dr. Ammerman also studies bacterial cell-surface enzymes that regenerate orthophosphate from organic phosphorous compounds in seawater.

The research of Dr. John R. Beers centers on the role of protozoans, and especially the ciliate components, in pelagic marine food web activities. In association with Dr. David C. Brownlee, he investigated the functional characteristics of ciliates, such as

their reproduction and feeding rates and the relationship of these to the distributional heterogeneity of the organisms. Of particular concern is the finest spatial scale, which may result from the ciliates' association with highly enriched aggregated seston materials, the larger of which can be important in sedimentation processes supplying food to deeper-dwelling and benthic organisms.

Dr. Angelo F. Carlucci is studying the amino acid metabolism, growth rates, and secondary production of the bacterioplankton in the water column including the benthic boundary layer, for example, the bottom 100 m of the water column and the upper 2 cm of sediment. Dr. Carlucci and a colleague measured these parameters in the 1,200-m-deep Santa Catalina Basin off the coast of southern California. Results indicate that the benthic boundary layer waters above 20 m off the bottom show little difference in bacterioplankton activities when compared to upper midwater depths of the basin. In general, there was increasing activity from the 20-m level down to the bottom, with the greatest values obtained directly at the sediment/water interface.

Dr. Bess B. Ward takes a sample from an incubation bottle in an experiment designed to measure methane's inhibitory effect on nitrifying bacteria.

Dr. Richard W. Eppley and associates completed a study of the length scale of phytoplankton patches on the continental shelf off southern California. Dr. Eppley and collaborators examined historical ship data from the eastern tropical Pacific Ocean. They used this data to estimate primary production from satellite meaurements of ocean chlorophyll. Studies of primary production and the sinking flux of organic particles in the Southern California Bight continue, with the collaboration of Edward H. Renger.

In a study of photoadaptation processes in marine phytoplankton, Dr. Osmund Holm-Hansen and graduate student Amir Neori have worked with others to investigate phytoplankton photobiology as a function of depth in the water column in the field, or of light intensity in laboratory cultures. Cells from low-light environments appear to be more efficient in utilizing the blue-green portion of the spectrum (470-560 nm) compared to cells exposed to high light intensities. Studies also show that action spectra of chlorophyll fluorescence during photosynthesis are essentially identical to action spectra for oxygen evolution.

Dr. George A. Jackson is studying water exchange across the sills of the Santa Monica-San Pedro Basin off Los Angeles as part of FCRG investigations on the flux of sestonic materials into the deep basins of the Southern California Bight. A study of interaction of kelp plants with their physical environment is being led by Dr. Jackson. He and his colleagues are modeling the growth of the giant kelp, *Macrocystis pyrifera*.

Dr. Michael M. Mullin and graduate student Jeffery M. Napp focus on the vertical distributions of phytoplankton and zooplankton, and how these distributions affect, and are in turn affected by, zooplankton grazing. Dr. Mullin also worked with colleagues in Japan on diel rhythms in zooplankton metabolism and reproduction, and with colleagues in Australia on the carbon budget of the Great Barrier Reef. He is developing biochemical analyses to compare the metabolic health of wild and hatchery-reared larval fish.

In association with other FCRG scientists, Freda M. H. Reid studied spatial and time patterns of phytoplankton species on the southern California shelf and in closer inshore waters. She has also cooperated with other Scripps scientists in an extended semiweekly study of phytoplankton at the Scripps Pier. Observations of the 1982-1984 El Niño event provided insight into the species composition of the pelagic algal populations associated with El Niño changes.

Dr. Bess B. Ward is focusing on marine nitrogen cycling. While on a cruise to the upwelling region off the coast of Peru, she investigated nitrification and denitrification in the oxygen minimum layer. She used chemical, biochemical, and microbiological methods to test the hypothesis that the rates and interactions of several micro-

bial nitrogen transformations are enhanced in the transition depths forming the boundaries of the oxygen minimum layer. Dr. Ward is also studying the interactions of methanotrophic and nitrifying bacteria as potential sinks for methane in the sea.

Dr. Peter M. Williams and a Woods Hole Oceanographic Institution colleague used radioactive carbon derived from atmospheric bomb testing in the 1950s and 1960s to trace the pathways of organic and inorganic carbon in the North Pacific Central Gyre. Studies on the cycling and budgets of organic matter in the nearshore basins off southern California continue. The basin program's goals are to assess the contributions of terrigenous and marine-derived organic material to the dissolved and particulate phases in the basin system, and to relate the composition of the organic phases to microbial and diagenetic processes occurring in the water column and sediments.

Marine Bio-Optics Group

The University of California Marine Bio-Optics Group is an IMR intercampus group with facilities at Scripps (coordinated by Karen S. Baker) and at UC Santa Barbara (directed by Dr. Raymond C. Smith). Research encompasses both theoretical and experimental marine bio-optics and makes use of at-sea capabilities, computer modeling, and remote sensing techniques. Multi-institutional and multidisciplinary programs elucidate ocean optics and phytoplankton dynamics on a variety of space and time scales. State-of-the-art instrumentation developed by the group includes a profiling instrument for measuring bio-optical water column properties to 200 m; an along-track measurement system for at-sea use; and a computer facility dedicated to image processing and data analysis. The Bio-Optical Profiling System (BOPS) now gives simultaneous optical, physical, and biological water column measurements. Satellite color and temperature imagery of east and west coastal areas permits global phytoplankton estimates as well as research into phytoplankton production.

Ocean Engineering Research Group

The Ocean Engineering Research Group (OERG), headed by Dr. Richard J. Seymour, undertakes applied research directed toward public and private use of the coast and coastal waters. The group operates the Coastal Data Information Program, which collects and analyzes nearshore ocean wave data along the West Coast and Hawaii. This information is processed in real time and made available to various users, including the National Weather Service for wave forecasts. Data are employed in the design of harbors, breakwaters, and offshore structures, and in the study of beach erosion. OERG is also investigating the application of real-time environmental data (water elevations, wind, waves, visibility, etc.) to improving the operation of ports and harbors.

Offshore industry is interested in using real-time wave and current data to improve the safety and efficiency of many operations, including resupply and crew changes, at-sea disposal of drilling fluids, and spill cleanup. A workshop for representatives of major oil companies was held at Scripps to plan how these data might be measured and disseminated.

The group continues studying the prediction of cross-shore transport by waves. Models available in the literature are being evaluated for accuracy in predicting the observations in a number of data sets acquired by OERG.

A series of beach and nearshore profiles was gathered from Dana Point to the Mexican border to evaluate seasonal trends in beach morphology. This research also involved the collection of sediment samples along the range lines to determine spatial and temporal variation of sand sizes.

Phytoplankton Resources Group

Headed by Dr. William H. Thomas, the Phytoplankton Resources Group continued to collect, isolate, and culture desert saline algae as potential biomass sources of solar energy. Two field trips were made to the deserts of eastern California and western Nevada, and approximately 100 strains of these algae are now in culture. They grow well at temperatures up to 40°C and at salinities of up to 40 grams dissolved salts per liter. When mass cultures are dense (1 gram dry weight per liter or above) they become light-limited even though incident light intensities are greater than 50 percent of sunlight. This indicates that this factor would limit production in outdoor ponds in the desert. However, even under light-limiting conditions, yields in the laboratory range up to 70 grams dry weight per square meter per day. Such yields are 10-20 times greater than yields of dry matter for higher plant crops, and thus the algae have great potential as a biomass resource for energy or protein.

Polar Research Program

Scientists in the Polar Research Program (PRP), directed by Dr. Holm-Hansen, are conducting biological/biochemical oceanographic studies in the Arctic and the Antarctic. Major emphasis is on the functioning and dynamics of the microbial food web, and on physiological adaptations related to the severe environmental conditions existing at high latitudes.

PRP personnel participated in the Norwegian PRO MARE program, which is a systems ecology project emphasizing description of Arctic food webs and the flux of organic carbon from phytoplankton to commercially important fish stocks. Members of the group visited northern and ice-free areas of the Barents Sea and the ice-covered Arctic Basin. Except for shallow bank areas, these Arctic waters were strongly stratified, which resulted in nutrient depletion in surface waters. Phytoplankton crops were generally over 90 percent nanoplankton, with relatively high concentrations of heterotrophic protozoan organisms.

PRP personnel also carried out field investigations in Peard Bay, Alaska, an important area for migratory birds and mammals. This large bay region receives an input of terrestrially derived organic carbon from the Kugrua River. Stable isotope analyses suggest that

some of this peat material may be incorporated into the marine food web.

Studies in the Antarctic included a month-long investigation of the dynamics of the bacterioplankton-phytoplankton populations close to Anvers Island, and sampling programs in Bransfield Strait and just north of Elephant Island. These latter studies were designed to assess grazing impact of zooplankton on phytoplankton populations and also to determine temporal and spatial variability in krill populations. Waters close to Palmer Station showed a typical spring bloom, as chlorophyll-*a* concentrations increased from approximately 1 g per liter in January to close to 30 g per liter in February. The bloom was predominantly autotrophic; very few heterotrophic microbial organisms were detected by microscopy.

California Sea Grant College Program

The California Sea Grant College Program, managed by Dr. James J. Sullivan, is headquartered at Scripps. The program's purpose is to accelerate sound development of marine resources by supporting a unique combination of marine research, education, and advisory activities throughout the state. This year 53 marine resources projects were conducted statewide—15 at Scripps—including a cooperative program with Baja California institutions.

Matthew B. Christiansen inserts a sampling rack into the Bottom Lander onboard R/V New Horizon.

B. Call

Other IMR Research Activities

Sargun Tont, continuing his analyses of coastal variables, found a significant but low correlation between sea levels and alongshore wind stress. Using variables like counts of diatom and dinoflagellate species, and measurements of sea level and surface temperatures, he has identified several El Niño events that occurred near the coast of southern California in the 1890s.

Dr. Mizuki Tsuchiya completed a study on the origin of the Atlantic equatorial 13°C water. The original type of the 13°C water is formed in the eastern sector of the South Atlantic subtropical gyre by vertical mixing of dense, cold, low-salinity water from the south and overlying, less dense, warm, high-salinity water. Relatively high-salinity water of intermediate density from the Indian Ocean may also contribute. The original 13°C water thus formed in the subsurface layer is transported northwestward along the northern edge of the subtropical gyre and flows into the equatorward North Brazilian Current along the coast of northern Brazil. In the equator region, this water returns to the east in the equatorial undercurrent and the subsurface north and south equatorial countercurrents and spreads over the entire equatorial Atlantic between 5°N and 5°S.

Seagoing Operations

R/V *New Horizon*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
07/05-07/26/84	CalCOFI 8407	San Diego Basin	Physical, chemical biological studies	San Diego	W. Bryan	T. Desjardins
08/13-09/01/84		San Diego Basin	Electromagnetic sounding	San Diego	C. Cox	T. Desjardins
09/10-09/20/84		San Diego Basin	Deep Tow	San Diego	F. Spiess	T. Desjardins
09/23-09/28/84		San Diego Basin	Benthic boundary layer biology	San Diego	K. Smith	T. Desjardins
09/30-10/13/84		San Diego Basin	Physiology of deep-sea animals	San Diego	J. Childress	T. Desjardins
10/18-11/09/84	CalCOFI 8410	Baja California	Physical, chemical biological studies	La Paz	G. Hemingway	T. Desjardins
11/11-12/05/84		La Paz Basin	Physical oceanography	La Paz	C. Winant/ N. Bray	T. Desjardins
12/06-12/10/84		Gulf of California	Physical oceanography	San Diego	C. Winant/ N. Bray	T. Desjardins
02/21/85		San Diego Basin	Test winches	San Diego	C. Winant	T. Desjardins
03/04-03/26/85		Gulf of California northern section	Physical oceanography	La Paz	C. Winant/ N. Bray	T. Desjardins
03/30-05/05/85		East Pacific Rise 6-12°N, 103°W	Dredging	San Diego	R. Batiza/ J. Bender	T. Desjardins
05/30-06/08/85		San Diego Basin	Benthic biology	San Diego	K. Smith	P. Munsch
06/24-06/27/85		San Nicolas Basin	Equipment test	San Diego	J. Ledwell	P. Munsch

TOTAL DISTANCE STEAMED: 26,673 nautical miles OPERATING DAYS: 205

R/V *Thomas Washington*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
06/09-07/09/84	Marathon III	Kodiak	Sea Beam	Kodiak	J. Ladd	R. Gregg
07/13-08/08/84	Marathon IV	Kodiak	Sea Beam	Honolulu	H. Menard/R. Hey	C. Johnson
08/11-08/21/84	Marathon V		Transit	Pago Pago		C. Johnson
08/22-09/26/84	Marathon VI	South Pacific/ South Atlantic	Sea Beam/ dredging	Mar del Plata	P. Lonsdale	C. Johnson
10/1-10/23/84	Marathon VII	South Atlantic	Physical-chemical oceanography	Montevideo	A. Gordon	L. Davis
10/26-11/17/84	Marathon VIII	South Atlantic	Sea Beam	Montevideo	G. Roden	C. Johnson
11/20-12/11/84	Marathon IX	South Atlantic	Sea Beam	Brazil	M. McCartney	C. Johnson
12/15/84-1/6/85	Marathon X	Mid-Atlantic Ridge	Sea Beam	Cape Town	J. Fox	C. Johnson
02/20-03/05/85	Marathon XI	South Atlantic	Sea Beam, current meters, CTD	Cape Town	J. Luyten	C. Johnson
03/07-03/28/85	Marathon XII	South Atlantic	Sea Beam, current meters, CTD	Cape Town	J. Luyten	C. Johnson
04/01-05/01/85	Marathon XIII	Tristan de Cunha	Sea Beam	Recife	J. Fox/K.Macdonald	C. Johnson
05/04-05/17/85	Marathon XIV		Transit	Balboa		C. Johnson
05/21-06/12/85	Marathon XV	East Pacific Rise	Seismics w/R/V *Conrad* & Sea Beam	San Diego	J. Orcutt/J. Detrick	T. Desjardins

TOTAL DISTANCE STEAMED: 71,987 nautical miles OPERATING DAYS: 370

R/V *Robert Gordon Sproul*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
09/06-09/09/84	Homecoming I	Yucatan Peninsula	Mammal study	Campeche	B. Le Boeuf	T. Beattie
09/09-09/15/84	Homecoming II	Yucatan Peninsula	Mammal research	Cozumel	B. Le Boeuf	T. Beattie
09/15-09/19/84	Homecoming III	Transit-Ensenada	Bird & fish census	Colon/Cristobal	K. Jacobsen	T. Beattie
09/20-09/29/84	Homecoming IV	Cristobal-Cabo San Lucas	Marine life census	Cabo San Lucas	K. Jacobsen	T. Beattie
09/30-10/03/84	Homecoming V	Transit-Ensenada	Marine census	Ensenada	K. Jacobsen	T. Beattie
10/29/84	Homecoming VI	Transit Ensenada-San Diego		San Diego	T. Collins	T. Beattie
11/17-11/18/84		Southern Calif.	Biology sampling	San Diego	D. Thistle	T. Beattie
12/11-12/13/84		San Diego Basin	Deep-sea barophilic bacteria	San Diego	A. Yayanos	T. Beattie
01/19-01/21/85		San Diego Basin	Benthic biology	San Diego	D. Thistle	T. Beattie
01/30/85		San Diego Basin	Deploy & recover fish trap	San Diego	K. Smith	T. Beattie
02/21/85		San Diego Basin	Equipment test	San Diego	J. Napp	T. Beattie
03/02/85		San Diego Basin	Student cruise	San Diego	R. Rosenblatt	T. Beattie
03/06/85		San Diego Basin	Equipment test	San Diego	P. Niiler	T. Beattie
04/08-04/09/85		San Diego Basin	Benthic biology	San Diego	A. Yayanos	T. Beattie
04/13-04/19/85		San Diego Basin	Equipment tests	San Diego	C. Cox	T. Beattie
04/22-04/29/85		San Diego Basin	Plankton studies	San Diego	J. Napp	T. Beattie
05/01-05/04/85		San Diego Basin	Plankton studies	San Diego	F. Azam/J. Ammerman	T. Beattie
05/08-05/15/85		San Diego Basin	Food chain	San Diego	E. Renger/R. Eppley	T. Beattie
05/18/85		San Diego Basin	Student cruise	San Diego	M. Mullin	T. Beattie
06/04-06/05/85		San Clemente Basin	Benthic biology	San Diego	A. Yayanos	T. Beattie
06/13-07/13/85		Gulf of California	Sea lion studies	San Diego	B. Le Boeuf	T. Beattie

TOTAL DISTANCE STEAMED: 10,932 nautical miles OPERATING DAYS: 96

R/V *Melville*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
09/04/84		San Diego Basin	Test benthic biology	San Diego	R. Wilson	R. Haines
09/13-10/04/84	Atlas Leg I	North of Hawaii	Test ops of Ishte platform	Honolulu	A. Olson	R. Haines
11/17-12/22/84	Atlas Leg I	140 Equator	Current meter Tropic Heat	San Diego	R. Knox	A. Phinney
01/06-01/13/85		San Diego Basin	Bottom Lander Expedition	San Diego	R. Jahnke	R. Haines
01/20-02/22/85	RIFTS I	East Pacific Rise	Deep Tow	Puntarenas	F. Spiess	R. Haines
02/28-03/30/85	RIFTS II	East Pacific Rise	Biology with *Alvin*	San Diego	J. Childress	R. Haines
04/16-04/28/85		Southern Calif.	Bottom Lander	San Diego	R. Jahnke	R. Haines
06/03-06/04/85			Inspection			
06/18-07/23/85	Alcyone Leg I	140 Equator	Current meters Tropic Heat	Honolulu	D. Luther	R. Haines

TOTAL DISTANCE STEAMED: 21,008 nautical miles OPERATING DAYS: 198

R/P FLIP

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
07/01-07/08/84		Hawaii	Equipment testing	Honolulu	R. Williams	D. Efird
10/21-11/10/84		Hawaii to San Diego	Equipment testing	San Diego	A. D'Amico	D. Efird
11/26-12/08/84		San Diego Basin	Sonar work	San Diego	R. Pinkel	D. Efird
01/31-02/03/85		San Diego Basin	Equipment testing	San Diego	R. Pinkel	D. Efird
03/25-03/29/85		San Diego Basin	Horizontal array	San Diego	F. Fisher	D. Efird

TOTAL DISTANCE TOWED: 3000 nautical miles OPERATING DAYS: 53

R/V *Ellen B. Scripps*

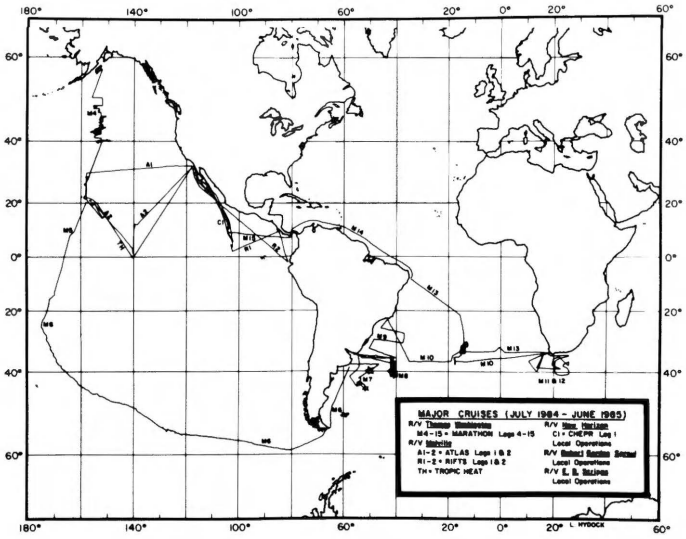
DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
06/30-07/07/84		Sea of Cortez	Mammal survey	Loreto	B. Le Boeuf	T. Beattie
07/07-07/09/84			Transit	La Paz	B. Le Boeuf	T. Beattie
07/13-07/24/84		La Paz-San Diego	Trawl & plankton sampling	San Diego	F. Tsuji/ R. McConnaughey	L. Zimm
07/27/84		San Diego Basin		San Diego	J. Napp	L. Zimm
08/01-08/06/84		San Diego Basin	Plankton layer study	San Diego	J. Napp	L. Zimm
08/07-08/14/84		San Diego Basin	Ocean processes	San Diego	L. Armi	L. Zimm
08/18-08/23/84		San Diego Basin	Seamount ecology	San Diego	A. Genin	L. Zimm
08/29-08/31/84		San Diego Basin	Niskin bottle sampling	San Diego	F. Azam/ J. Ammerman	L. Zimm

TOTAL DISTANCE STEAMED: 4,124 nautical miles OPERATING DAYS: 47

RESEARCH VESSELS OF SCRIPPS INSTITUTION OF OCEANOGRAPHY

	MELVILLE	*NEW HORIZON*	*ROBERT GORDON SPROUL*	*THOMAS WASHINGTON*	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

1984-85 Total nautical miles steamed: 137,725 1984-85 Total operating days: 969 *Depends on towing vessel **With berthing vans



Graduate Department

The Graduate Department of the Scripps Institution of Oceanography offers instruction leading to Ph.D. degrees in oceanography, marine biology, and earth sciences. Because of the interdisciplinary nature of the ocean sciences, the department provides a choice of seven curricular programs through which the student may pursue a five-year Ph.D. degree. Each of these curricular groups has requirements for admission in addition to the departmental requirements. The curricular programs are described below. For admission requirements 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. Research and instruction in this curriculum range from food-chain dynamics and community structure to taxonomy, behavior, physiology, and zoogeography of oceanic organisms.

Graduate student Sandor E. Kaupp (below) dissects a juvenile English sole, Parophrys vetulus, *as part of his studies on biochemical changes in red and white muscle during development and adaptive responses to exercises. . . . Graduate student Jill M. Whitman (opposite page) examines benthic foraminifera as part of her thesis work.*

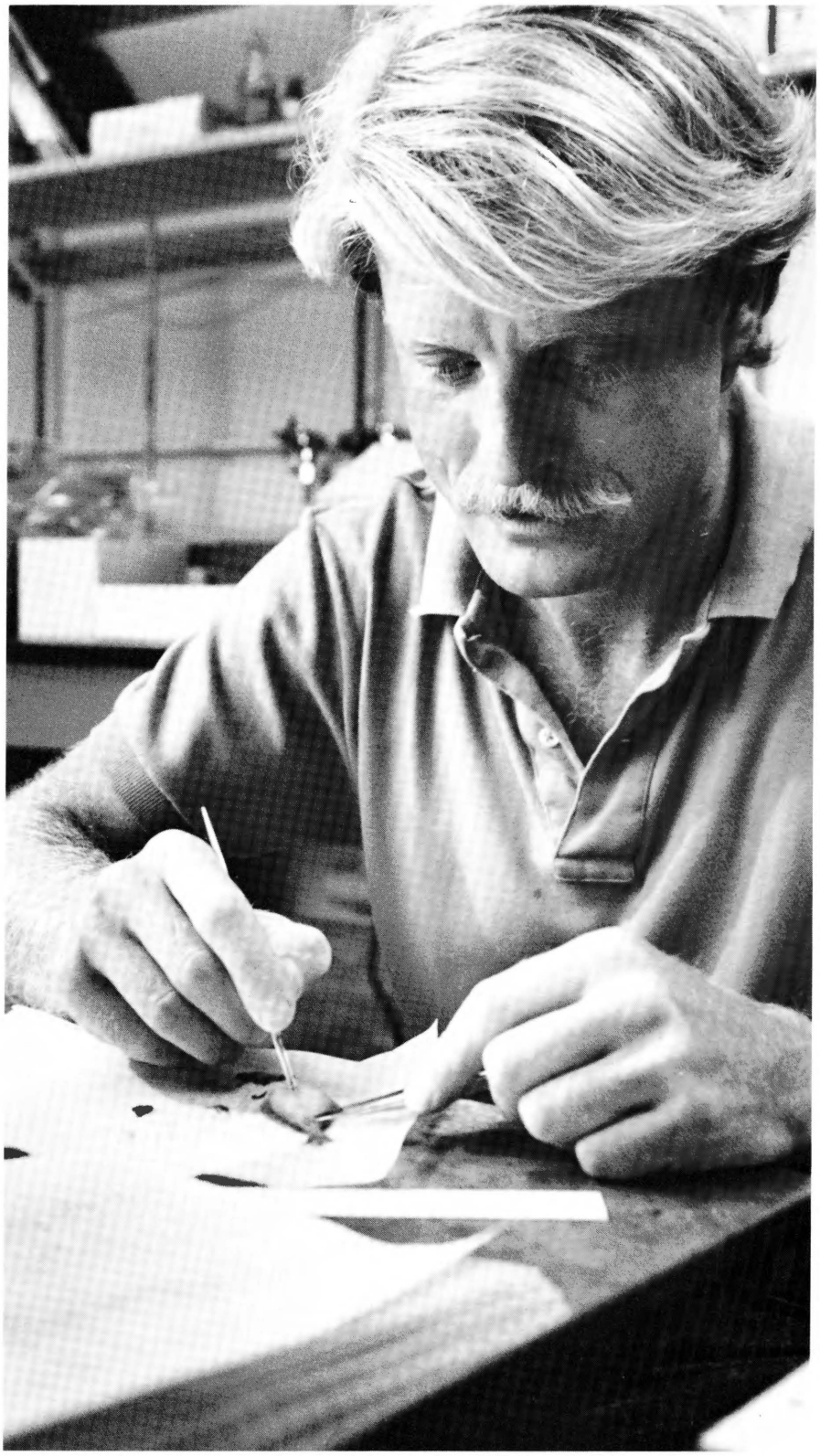
Geological Sciences. This curriculum applies observational, experimental, and theoretical methods to the understanding of the solid earth and solar system and their relationship to the ocean and the atmosphere. Principal subprograms are marine geology and tectonics, sedimentology, micropaleontology and paleooceanography, 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. The program assists students in understanding the nature of the earth and in mastering 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, the marine atmosphere, and on the seafloor. Research programs are based on the interactions of seawater components with the atmosphere, 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 by the ocean; the distribution and variation of properties of the ocean; 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 1984, 30 new students were admitted to graduate study. Of these, 7 were in marine biology, 6 in geological sciences, 6 in marine chemistry, 3 in geophysics, 4 in physical oceanography, 3 in applied ocean sciences, and 1 in biological oceanography. Enrollment at the beginning of the academic year was 184. Eleven Master of Science degrees and 24 Doctor of Philosophy degrees were awarded by UC San Diego to the students listed below.

Doctor of Philosophy Degrees Awarded, with Titles of Dissertations

Earth Sciences

Kenneth C. Creager, "Geometry, Velocity Structure, and Penetration Depths of Descending Slabs in the Western Pacific."

Giovanni B. Marchisio, "Exact Nonlinear Inversion of Electromagnetic Induction Soundings."

Jeffrey J. Park, "Applications of the Galerkin Formalism in the Coupling of the Earth's Free Oscillations."

Mark A. Riedesel, "Seismic Moment Tensor Recovery at Low Frequencies."

Patricia A. Schultejann, "Late Mesozoic and Cenozoic Tectonic History of South Central California."

Paul M. Stout, "Chemical Diagenesis of Pelagic Biogenic Sediments from the Equatorial Pacific."

Marine Biology

R. Douglas Fields, "Structural and Functional Plasticity of the Ribbon Synapse in the Ampullae of Lorenzini."

Mark J. Grygier, "Comparative Morphology and Ontogeny of the Ascothoracida, a Step Toward a Phylogeny of the Maxillopoda."

Patrick M. McDonough, "Factors That Influence Bubble Formation in Crustaceans and Fish Following Decompression from Hyperbaric Gas Equilibrations."

Giuseppe Notarbartolo-di-Sciara, "A Revisionary Study of the Genus *Mobula* Rafinesque 1810, with the Description of a New Species, and Natural History Notes on East Pacific Mobulids."

Valerie J. Paul, "The Natural Products Chemistry and Chemical Ecology of Tropical Green Algae of the Order Caulerpales."

Jeff Schweitzer, "Studies of the Elasmobranch Central Electrosensory System, with Emphasis on Functional Organization of the Electroreceptive Midbrain in the Thornback Ray."

Alan L. Shanks, "The Effects of Larval Behavior and Distribution on the Cross Shelf Dispersal of Coastal Crabs."

Oceanography

Mark Allen Baker, "Sampling Turbulence in the Stratified Ocean: Statistical Consequences of Strong Intermittency."

John L. Bullister, "Atmospheric Chlorofluoromethanes as Tracers of Ocean Circulation and Mixing: Measurement and Calibration Techniques and Studies in the Greenland and Norwegian Seas."

Andrew C. Campbell, "Geochemistry of Hydrothermal Clouds in the Guaymas Basin, Gulf of California."

Brad K. Carté, "Cytotoxic Metabolites from Marine Organisms."

Stephen Laurence Elgar, "Shoaling Surface Gravity Waves."

P. Michael Kosro, "Shipboard Acoustic Current Profiling during the Coastal Ocean Dynamics Experiment."

Mustafa O. Moammar, "Marine Diagenesis of Hydrothermal Sulfide."

Jeffrey A. Nystuen, "Underwater Ambient Noise Measurements of Rainfall."

Paul A. Schiffelbein, "Stable Isotope Systematics in Pleistocene Deep-Sea Sediment Records."

Leslie J. Snider, "Demersal Zooplankton of the Giant Kelp *Macrocystis pyrifera:* Patterns of Emergence and the Population Structure of Three Gammarid Amphipod Species."

Spahr C. Webb, "Observations of Seafloor Pressure and Electric Field Fluctuations."

Master of Science Degrees

Earth Sciences

David F. Naar
Matthew O. Tanzer

Marine Biology

Arild Folkvord

Oceanography

C. Anne Dorkins
Marcelo A. Esteban
Jorge E. Laguna
Justin Lancaster
Patricia A. Matrai
Victor H. Marin
Don A. Smith
Dennis L. Strand

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 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 superconducting IBM nuclear magnetic resonance spectrometer; a Leco CO_2 and SO_2 analyzer; a Coulo metrics total carbon/CO_2 analyzer; a P/E radio-recording computerized infrared spectrometer; a P/E UV-VIS 124 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 m^2) 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 m^2) 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.

Diving Facility. The research diving program is housed in two separate facilities that contain the mechanical gear, wet equipment storage locker, 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 throughout the oceans of the world, including the Antarctic.

Hydraulics Laboratory. This laboratory has a wind-wave channel 43x2.4x2.4 m, with a tow cart for instruments and models; a two-layer stratified flow channel, test section 1.1x1.1x16 m; a 15x18-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 that consists of a 6x12x3-m concrete basin, a 10x1x1-m fluidizing channel, three sand-storage and calibration tanks each 4 m high by 5 m in diameter, all serviced with a high-flow, slurry pumping system; a 16-m oscillating flow tunnel; and an insulated, refrigerated, cylindrical seawater tank 10 m deep and 3 m in diameter equipped with an artificial lighting system. 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 20 acres of Mission Bay marshland belong to the university and constitute a marsh preserve and wildlife refuge designated for teaching and research. The reserve is the last fragment of the once extensive Mission

At marine ship-to-shore radio station WWD (below) Timothy J. Hoskins sends Morse code to R/V Thomas Washington. ***Background, Terence E. Clark talks with** R/V* Melville *about an electrical problem. . . . Timothy J. Hoskins (opposite top) sends Morse code message to R/V* Thomas Washington. . . . *Albert Yatrofsky (opposite bottom) sends teletype message.*

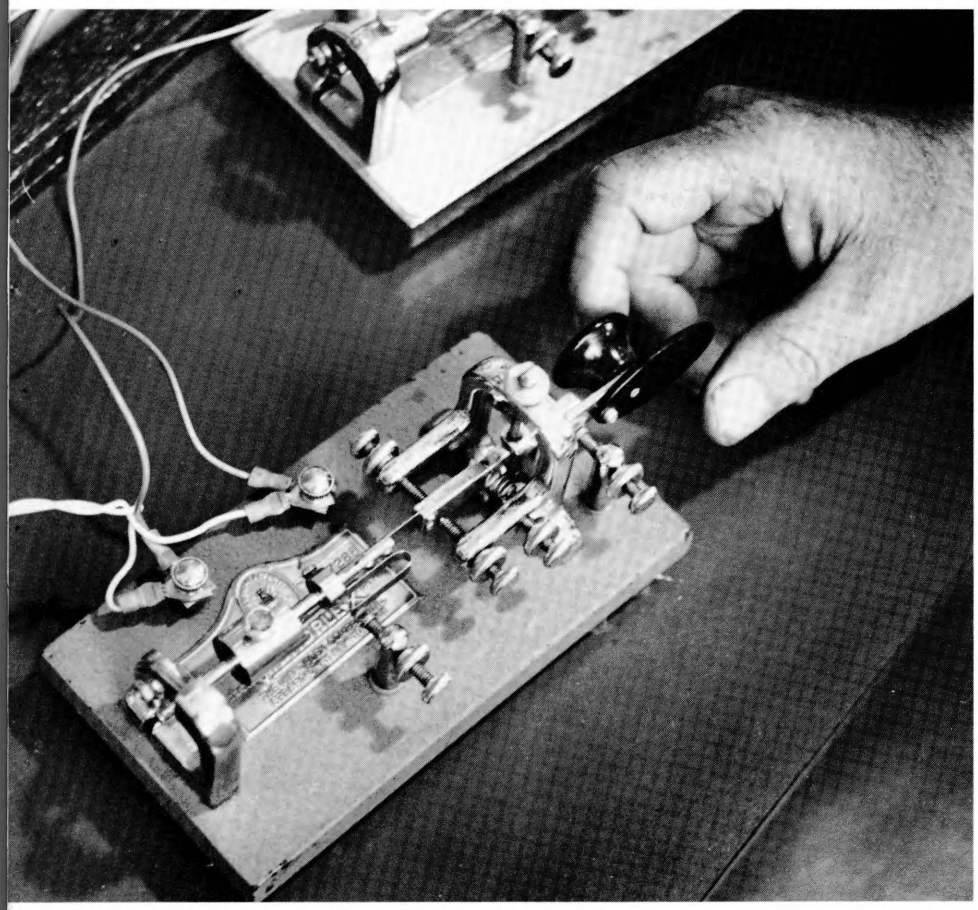
Bay salt marsh. This property is one of 26 natural reserves used for teaching and research in the University of California Natural Land and Water Reserve System. A small laboratory is located on the preserve. For more information write to the reserve manager, A-001, in care of Scripps.

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.

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 various 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 provided to the fishing fleet as well as to scientific vessels. Western Union services (TWX-Telex) are provided to the San Diego campus. WWD is now in the process of computerizing 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 8x15-m enclosed platform in water 40 m deep and offers an unobstructed range of 1,372 m.

Satellite-Oceanography Facility. This facility enables oceanographers to directly 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 system 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, 1600, or 6250 bpi densities 317 cm per second assure complete versatility. A high-resolution color display station allows the user 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.

Scripps Library. The library has outstanding collections in oceanography, marine biology, and marine technology. It also specializes in publications on atmospheric sciences, fisheries, geology, geophysics, and zoology. The library currently receives more than 3,600 serial titles and has a cataloged collection of more than 185,000 volumes, including an extensive documents, reports, and translations collection, and a rare book collection with numerous accounts and journals of famous voyages of discovery. There is also a large map and chart collection emphasizing nautical information.

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.

Seawater System. Pumps located on Scripps Pier deliver seawater to the laboratories and aquaria of Scripps and the Southwest Fisheries Center. The seawater system utilizes 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 Services Unit. The Shipboard Technical Support Services Unit is an amalgamation of several groups that provide shipboard technical support for both Scripps and the oceanographic community at large. This group provides technical and data collection services aboard Scripps's research vessels, supplying and maintaining shipboard scientific facilities (computers, geological, biological, physical, and chemical data acquisition systems), logistic support for these facilities, and postcruise data processing distribution and archiving. Shipboard Technical Support Services also furnish 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, geological data center, and the physical and chemical oceanographic data facility.

The Shipboard Computer Group is composed of programers and engineers who support VAX/UNIX computers ashore and at sea through programing, interface design, and maintenance. A shore-based VAX 750, available for use by the Scripps community, supports the VAX 730's installed 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.

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

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.

The Oceanographic Data Facility (ODF) collects data and samples for investigators from Scripps and other institutions. ODF also maintains an inventory of water samplers and other equipment, which is available at cost to qualified users. The more sophisticated or costly equipment 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 CO_2 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.

A new IBM 9000 computer-based data acquisition system has undergone software development for both shipboard and shore-based data processing. This system was used on a Pacific cruise to 24°N. It is capable of block averaging data in real time and provides scientists with preliminary data output and data plotting facilities aboard ship. Tape drives, plotters, and printers are in use with both seagoing and shore-based systems.

Many of the Scripps scientific collections have also been made part of the Shipboard Technical Support Services Unit. For further information see the Special Collections section.

Special Collections

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.

Aquarium-museum scientific staff provides aid and information on marine organism maintenance, fish diseases, local species distributions, and other related topics to UCSD and SIO researchers. Through its collecting facility, the aquarium supplies scientists with living specimens.

This year more than 37,000 students in educational groups toured the aquarium-museum. The aquarium is open to the public daily; admission is free.

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 include the following two parcels adjacent to Scripps that are also part of the Scripps Shoreline, Knoll and Underwater 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 proper 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 km^2 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.

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. Several catalogs of holdings (Decapod and Stomatopod Crustacea [SIO Ref. No. 77-9], Brachiopoda [SIO Ref. No. 78-19], and Echinodermata [SIO Ref. No. 82-5]), as well as specimens, are available to qualified students and researchers.

Deep Sea Drilling Project (DSDP) Core Repository. Scripps (under subcontract from the Ocean Drilling Program) houses the West Coast Repository for cores collected by DSDP from the Pacific and Indian oceans. Core samples are made available to qualified researchers throughout the world under policies established by the National Science Foundation and implemented through the Joint Oceanographic Institutions and Texas A & M University.

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. Most of the geological/geophysical data collected by Scripps vessels are processed and archived here. 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. Seismic profiler records are microfilmed, blown back at reduced scale, and reassembled by geographic area to permit rapid retrieval and evaluation. Index track charts, with overlays of the various data types, contain more than a million nautical miles of Scripps cruises, as well as tracks of DSDP's *Glomar Challenger*. The data center also maintains a multidisciplinary index of all samples and measurements made on major Scripps cruises.

Marine Botany Collection. A small herbarium of marine benthic algae is composed of 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 60,000 documented whole zooplankton samples are accessioned holdings from the continuous CalCOFI program, expeditions, 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 northeastern Pacific, but an increasing number of samples are also available from other oceanic and continental slope regions. The collection includes identified specimens for some of the major taxonomic groups. Samples are supplemented with physical and chemical data.

Marine Vertebrates. This collection contains more than 2 million specimens, with 3,200 cataloged species, including 128 primary types.

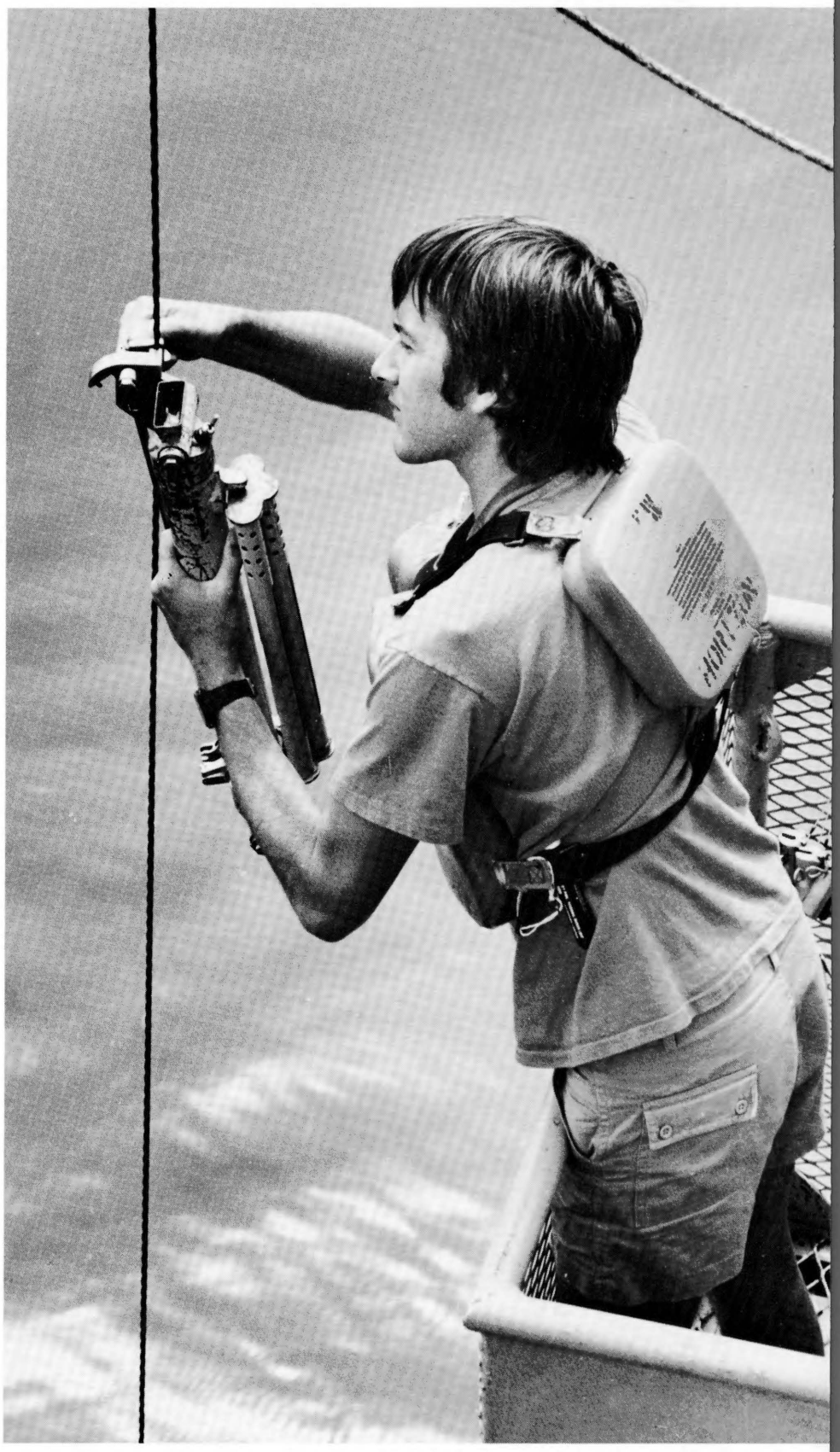
Approximately 500 collections are added each year. Although the collection is worldwide, it specializes in deep-sea and eastern Pacific shorefishes. It contains large holdings of shorefishes from the Gulf of California and Panama and an extensive skeletal collection of dried preparations and cleared-and-stained specimens in glycerin.

Oceanographic Data Archives. Tide-gage records have been taken daily from the Scripps Pier since 1925. Records for the current month are held at the Scripps Diving Locker. Monthly tide-gage records from 1947-1967 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 Datums and Information Branch, James R. Hubbard, C-233, NOAA/NOS, 6011 Executive Blvd., Rockville, MD 20852.

Data from more than 20,000 hydrographic casts from Scripps cruises are managed by the Physical and Chemical Oceanographic Data Facility. 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 the 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.

Dr. John L. Bullister attaches a Nansen bottle to a line aboard R/V New Horizon.



E. L. Venrick

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 1985. 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: University of California Press, 2223 Fulton Street, Berkeley, California 94720.

The most recent volumes are listed below.

v. 24 **Johnson,** G. David. The Limits and Relationships of the Lutjanidae and Associated Families. 1981. 117p.

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.

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 *CalCOFI Reports Series.* Maps of physical, chemical, climatological, and biological parameters measured by CalCOFI researchers during the program's 36-year history are published irregularly in the *CalCOFI 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

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

The articles listed below were published in the 1984 volume and may 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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AM—Aquarium-Museum
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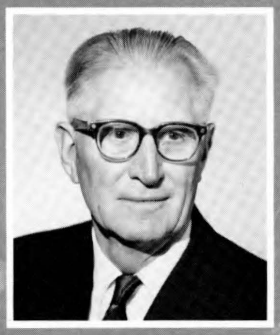
CS—California Space Institute
CCS—Center for Coastal Studies
DO—Director's Office
DSDP—Deep Sea Drilling Project
D-SIO—Department Scripps Institution of Oceanography
EECS—Electrical Engineering and Computer Sciences
GRD—Geological Research Division
IGPP—Institute of Geophysics and Planetary Physics
IMR—Institute 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

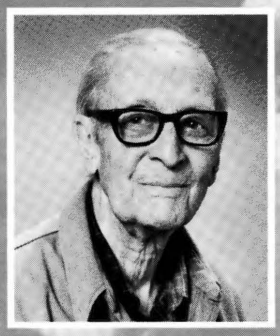
In Memoriam

Robert E. Gorman. July 19, 1984. He worked at the Marine Physical Laboratory for 20 years and was a development technician when he retired from Scripps in 1982.

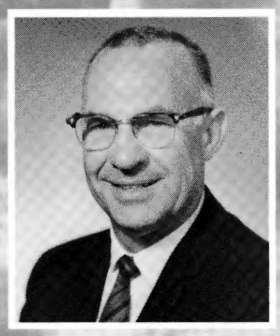
Martin W. Johnson. November 28, 1984. Dr. Johnson joined Scripps in 1934 and remained for 50 years. He was noted for his studies of the distribution and life histories of marine crustaceans and planktonic organisms. Dr. Johnson was one of three authors of the major oceanographic text *The Oceans: Their Physics, Chemistry and General Biology.*



Francis P. Shepard. April 25, 1985. Dr. Shepard was affiliated with Scripps from 1937 until his death. Noted as "the father of marine geology," Dr. Shepard was the first to center his research on the landscapes beneath the seas. His pioneering textbook, *Submarine Geology*, was followed by many college and high school texts.



Frank E. Snodgrass. June 29, 1985. Frank Snodgrass worked at Scripps as a research engineer for 23 years until his retirement in 1976. Many oceanographic techniques that are now taken for granted—digital recording, portable seagoing laboratories—are products of his inventive mind.



Anna (Spurlock) Tokar. Anna Tokar was an administrative assistant in the Marine Life Research Group/ Institute of Marine Resources business office. She worked at Scripps from 1967 through 1978.

Carr Tuthill. November 1984. Carr Tuthill joined the aquarium-museum staff in 1953. He was aquarium curator when he retired in 1968.

Appendix C †

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Appendix D *

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  Department of Fish and Game
  Department of Water Resources
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Commerce, Department of
  National Bureau of Standards
  National Oceanic and Atmospheric Administration
Defense, Department of
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  Army, Department of the
    Army Corps of Engineers
  Defense Mapping Agency
  Navy, Department of the
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    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
  National Park Service
  U.S. Geological Survey
National Aeronautics and Space Administration
National Science Foundation

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*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 E

Awards and Honors

Dr. Hassan Aref
Received Presidential Young Investigator Award from the National Science Foundation.

Dr. Farooq Azam
Received the Rosenstiel Award in Oceanographic Science from the University of Miami.

Dr. Wolfgang H. Berger
Received the 1984 A. G. Huntsman Award of Excellence in Marine Science from the Bedford Institute of Oceanography, Nova Scotia.

Dr. J. Freeman Gilbert
Received the Arthur L. Day Medal from the Geological Society of America.

Dr. Miriam Kastner
Received the 1984 Service through Chemistry Award from the Orange County Section of the American Chemical Society.

Dr. Walter H. Munk
Awarded a National Medal of Science by President Reagan.

Dr. Jerome Namias
Received the Marine Technology Society's Compass Distinguished Achievement Award for 1984.
Received the UC San Diego Chancellor's Associates Merit Award for Excellence in Research.

Dr. William A. Nierenberg
Awarded the degree of Doctor of Science, *honoris causa* by New Jersey Institute of Technology.

Joseph L. Reid
Received the National Oceanographic Data Center's first annual service award.
Elected a fellow of the American Association for the Advancement of Science.

Dr. Roger R. Revelle
Received a 1985 Golden Plate Award from the American Academy of Achievement.

Dr. Fred N. Spiess
Elected a member of the National Academy of Engineering.

Dr. Robert E. Stevenson
Received the Meritorious Civilian Service Award from the U.S. Navy.

Dr. Kenneth M. Watson
Elected a fellow of the American Association for the Advancement of Science.

Appendix F

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State Superintendent of Public Instruction, William Honig
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Agency	Scripps Institution of Oceanography	Cal Space Institute	Institute of Geophysics and Planetary Physics	Institute of Marine Resources	Total	Percentage of Total
FEDERAL GOVERNMENT						
National Science Foundation	$13,785,510	239,330	1,570,733	709,009	16,304,582	32.2
Navy, Department of the	11,601,037	77,527	508,964	31,704	12,219,232	24.1
National Aeronautics and Space Administration	424,154	578,927	32,105	69,075	1,104,261	2.1
Army, Department of the	2,523	——	——	627,837	630,360	1.2
Energy, Department of	62,989	——	——	355,041	418,030	1.0
Air Force, Department of the	323,700	——	94,072	——	417,772	1.0
Interior, Department of the	48,441	——	247,558	——	295,999	0.5
Health and Human Services, Department of the	653,449	364	——	2,631	656,444	1.2
Commerce, Department of	741,883	——	10,245	934,137	1,686,265	3.3
Other	179,885	——	15,126	8,031	203,042	0.4
Total Federal Government	27,823,571	896,148	2,478,803	2,737,465	33,935,987	67.0
STATE AND UNIVERSITY FUNDS	9,459,465	688,535	383,655	783,429	11,315,084	22.4
LOCAL GOVERNMENT	2,214	——	——	38,358	40,572	0.1
PRIVATE GIFTS AND GRANTS	3,093,110	9,077	183,007	331,727	3,616,921	7.2
ENDOWMENT FUNDS	493,068	2,111	24,155	3,195	522,529	1.0
SERVICES, RESERVES, AND MISC.	946,865	–307	8,935	220,335	1,175,828	2.3
Total Current Funds Expenditures	$41,818,293	1,595,564	3,078,555	4,114,509	50,606,921	100.00

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

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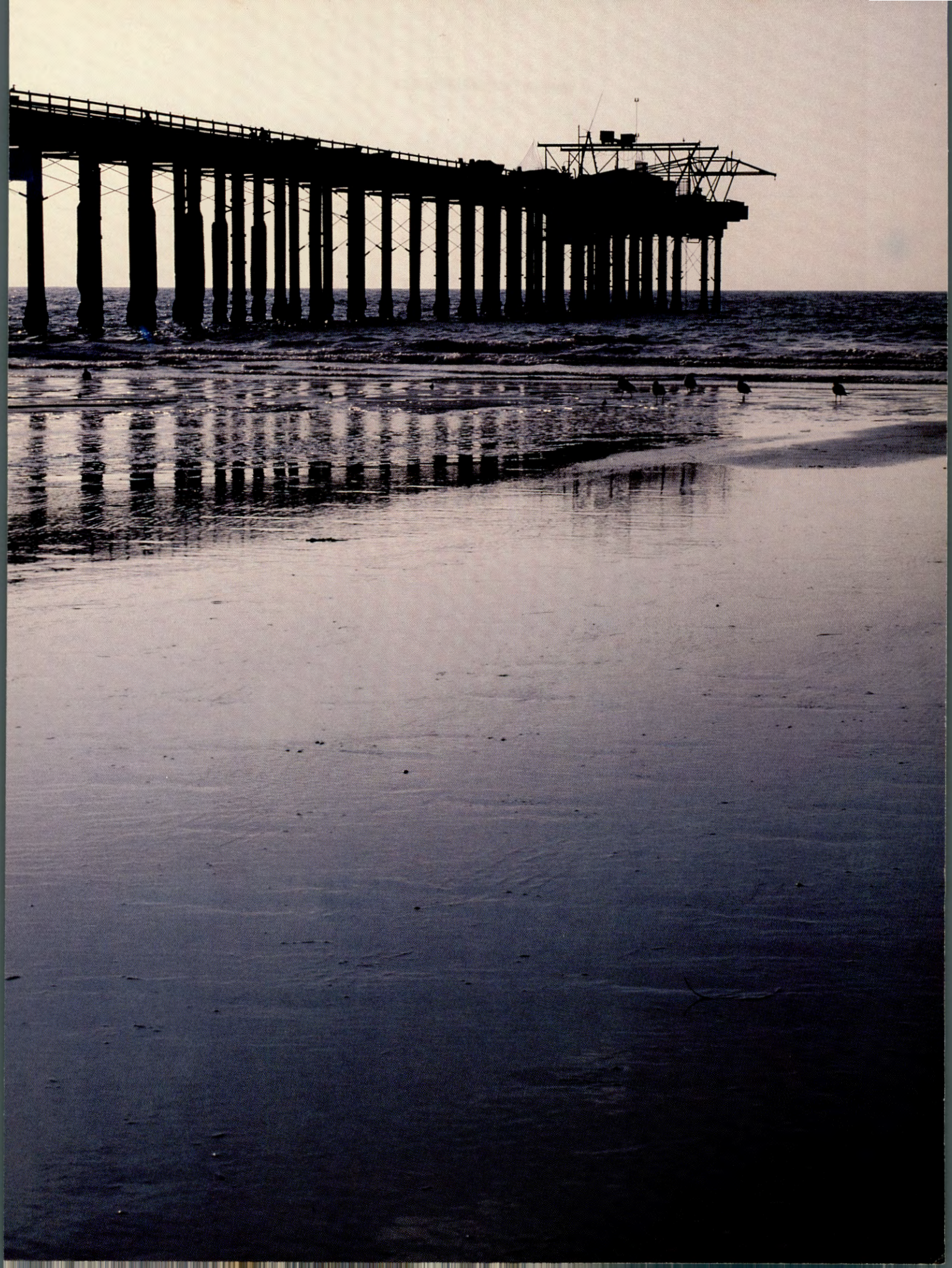
Cover:
Graduate student S. Craig Cary uses laser to measure growth in the clam Lucinoma aequizonata.

Outside Back Cover:
Bottom Lander is hoisted back aboard R/V New Horizon *after a recent test in the San Diego Trough.*

Inside Back Cover:
Evening view of soon-to-be-replaced Scripps Pier.



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