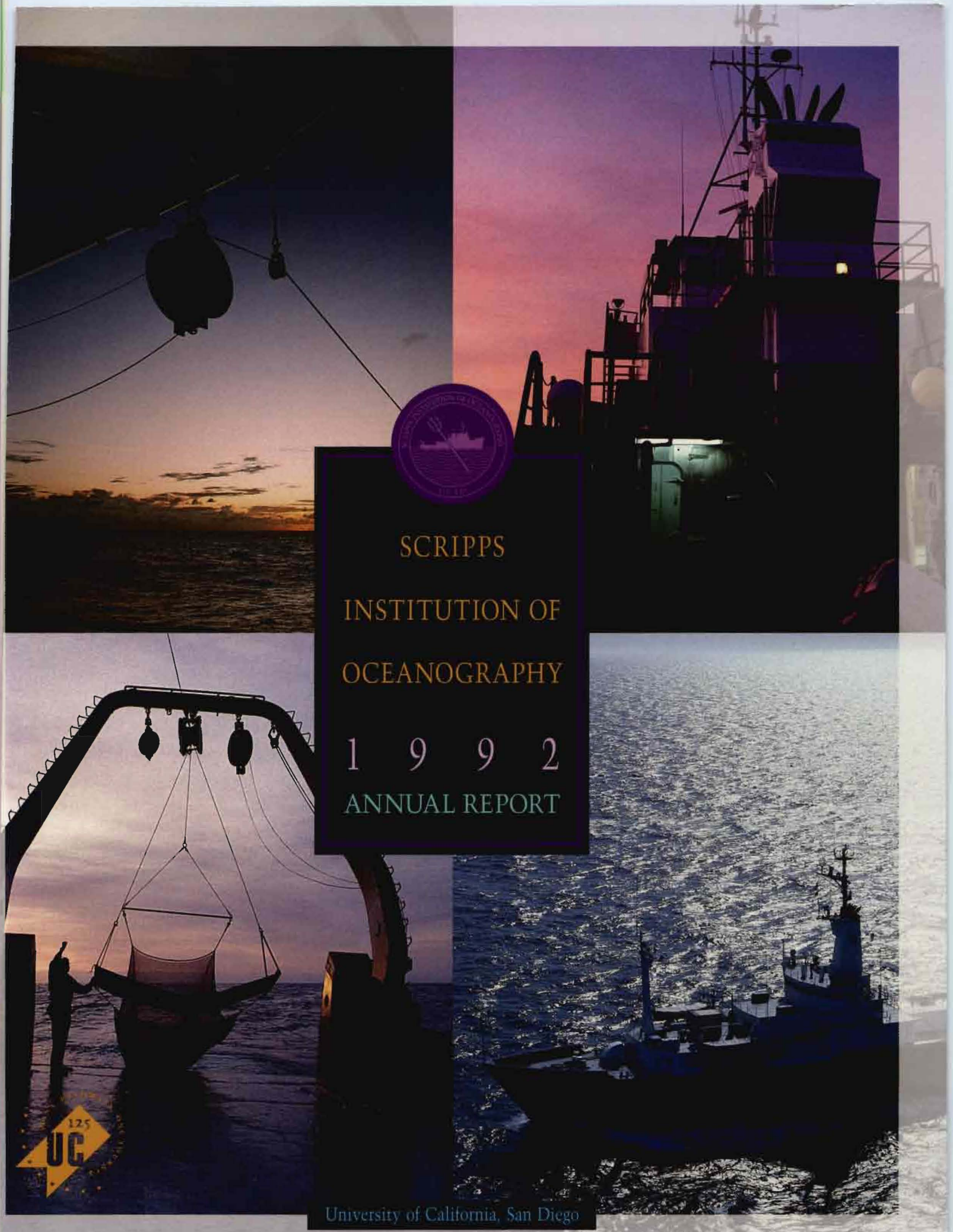
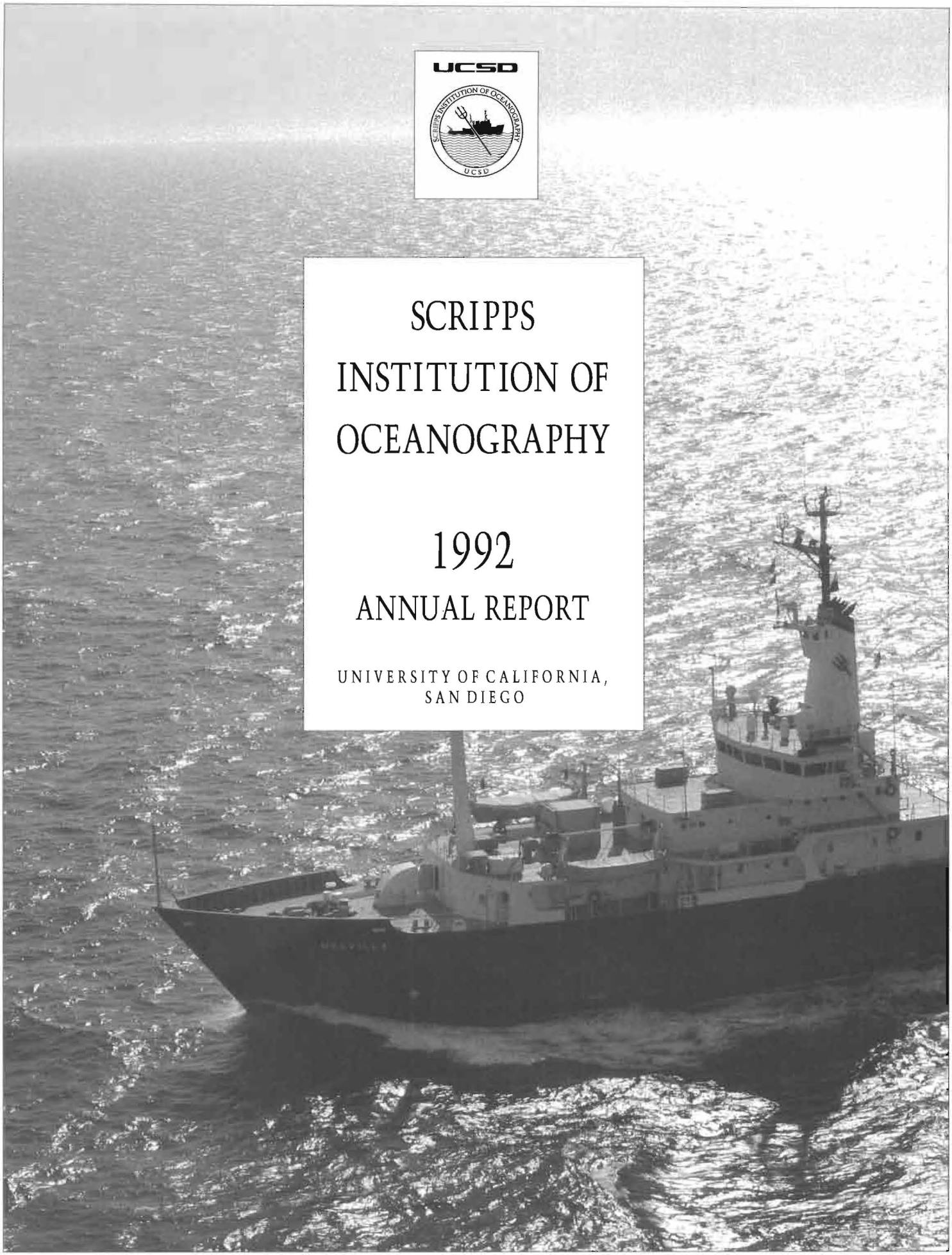


SCRIPPS INSTITUTION OF OCEANOGRAPHY

1992 ANNUAL REPORT

University of California, San Diego

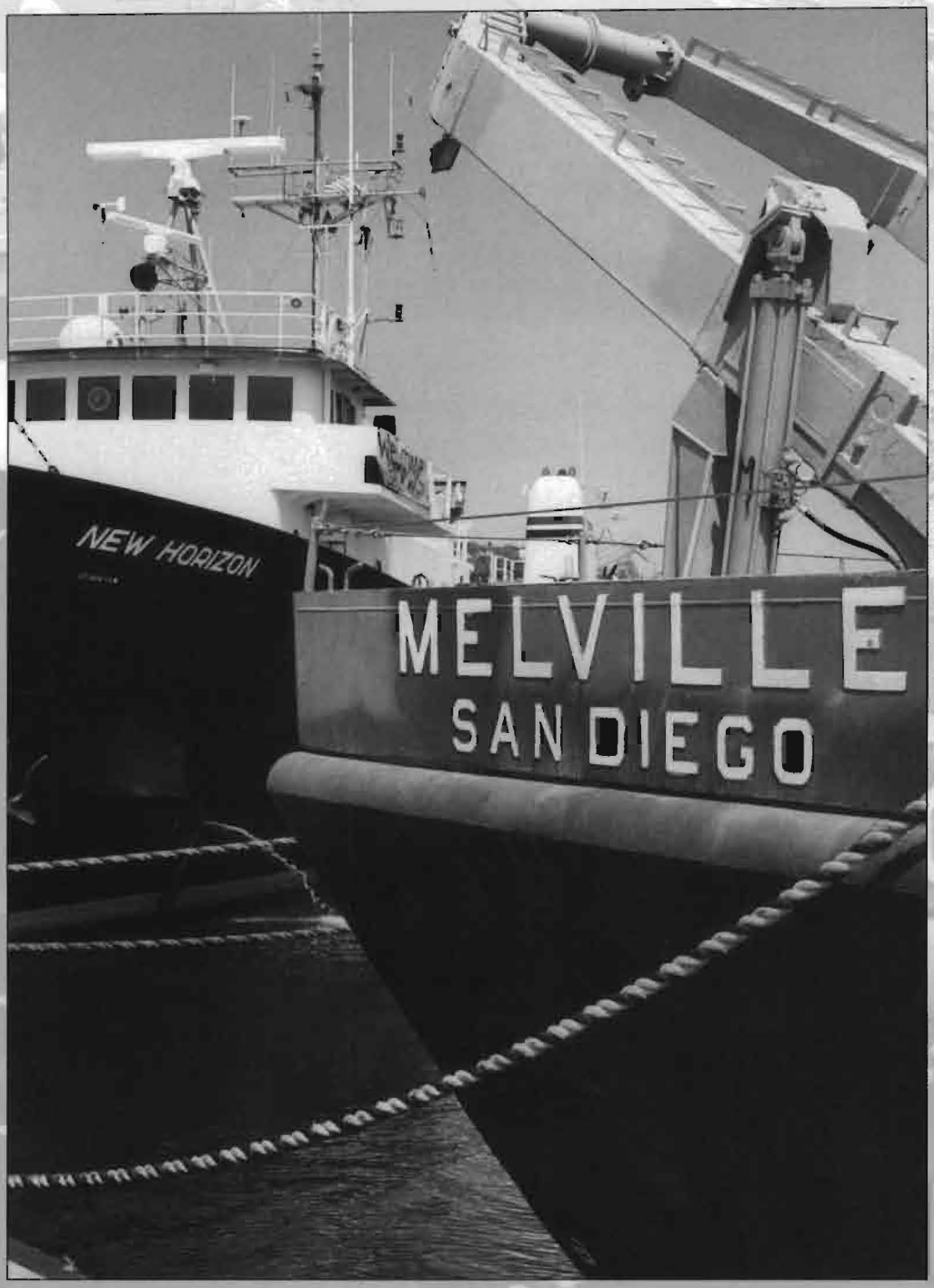


SCRIPPS INSTITUTION OF OCEANOGRAPHY

1992 ANNUAL REPORT

UNIVERSITY OF CALIFORNIA, SAN DIEGO

R/V *New Horizon* and R/V *Melville* in port at Nimitz Marine Facility.



This is the University of California, San Diego, Scripps Institution of Oceanography 1992 Annual Report (for the year ending June 30, 1992). ISSN 1046-9443. A major portion of the work reported herein was supported by the National Science Foundation and the Department of the Navy. For more information on the institution please write to University of California, San Diego, Scripps Institution of Oceauography, Technical Publications 0233-B, 9500 Gilman Drive, La Jolla, California 92093-0233.

C O N T E N T S

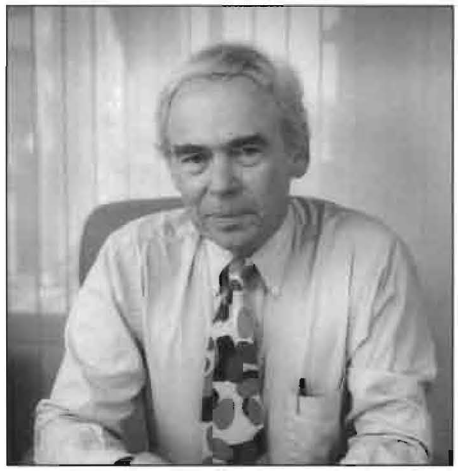
R/V *Melville*

Director's Council*

Linden Blue ..... Vice Chairman, General Atomics
Walter Cronkite ..... Senior Correspondent, CBS, Inc.
Ted Danson ..... Actor; Founder, American Oceans Campaign
Robert Frosch ..... Vice President, General Motors Research Laboratory
Eugene Fubini ..... Consultant
Cecil Green ..... Founder, Texas Instruments
Gordon Moore ..... Chairman of the Board, Intel Corporation
David Packard ..... Chairman, Hewlett-Packard Company
Burton Richter ..... Nobel Laureate; Director, Stanford University Linear Accelerator Center
William Ruckelshaus ..... Chairman of the Board, Chief Executive Officer, Browning-Ferris Industries
Jonas Salk ..... Founding Director, Salk Institute

*Current June 30, 1992

THE PAST YEAR HAS BEEN one of extraordinary pressure not only on Scripps but on the entire U.S. scientific and technological community. The end of the cold war created a new national agenda focusing on environmental concerns, improvements in education and training, and the health and social well-being of our citizens. Research-intensive universities have been asked to become more responsive to the crucial needs of society.



At the same time, Scripps has been affected by the current economic downturn that has created stiffer competition for federal funds, smaller federal R&D budgets, and a reduction in the base state support budget for education and research programs.

A few years ago, recognizing that difficulties such as these were likely to arise, deliberate actions were taken to mitigate or forestall their effects on the institution. These included diversifying federal support by seeking a broader range of funding agencies, shifting emphasis in research programs to accommodate the new demands of society, increasing reliance on private support and establishing new structures to facilitate submission of multiple proposals.

Our efforts resulted in a 23% increase in federal support dollars over the last year and a number of new, large programs being initiated. A cooperative arrangement between the National Oceanic and Atmospheric Administration and Scripps called the Joint Institute for Marine Observations (JIMO) has been successfully launched. Scripps scientists continue to provide leadership in a number of government sponsored research efforts to understand the coupled ocean-atmosphere system.

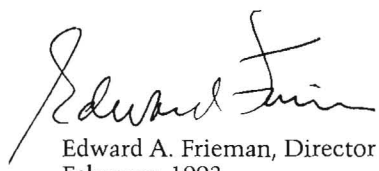
While federal funds support many of the institution's research efforts, support from philanthropic organizations, corporations, and individuals has played a major role in maintaining the vitality of Scripps programs. Substantial endowments, such as one from the Mellon Foundation (for the SIO Innovative Research Endowment Fund) and one from the Tode Foundation are just two examples of this support.

To aid us in moving the institution forward the Scripps Director's Council, a group of distinguished individuals serving as an advisory body, provides expertise, counsel, and guidance in all areas of institutional advancement.

Central to the Scripps outreach program was the opening of the Stephen Birch Aquarium-Museum. Unique for its association with an oceanographic institution, the facility serves as an information resource and liaison between Scripps's scientists and the projected 500,000 annual visitors. To create a means for the public to learn about and support our research, education, and outreach missions, a Scripps Associates program was initiated. We are pleased to say that the associates number nearly 6,000 members from all areas of the United States.

The unique strengths of the institution have made it possible for us to protect the quality of our basic research and preserve the intellectual milieu in which it flourishes, as well as to engage in globally important investigations. The face of Scripps is ever changing. This year saw many retirements and new faculty appointments. We welcomed a new Deputy Director for Scientific Affairs, Dr. Mary Altalo.

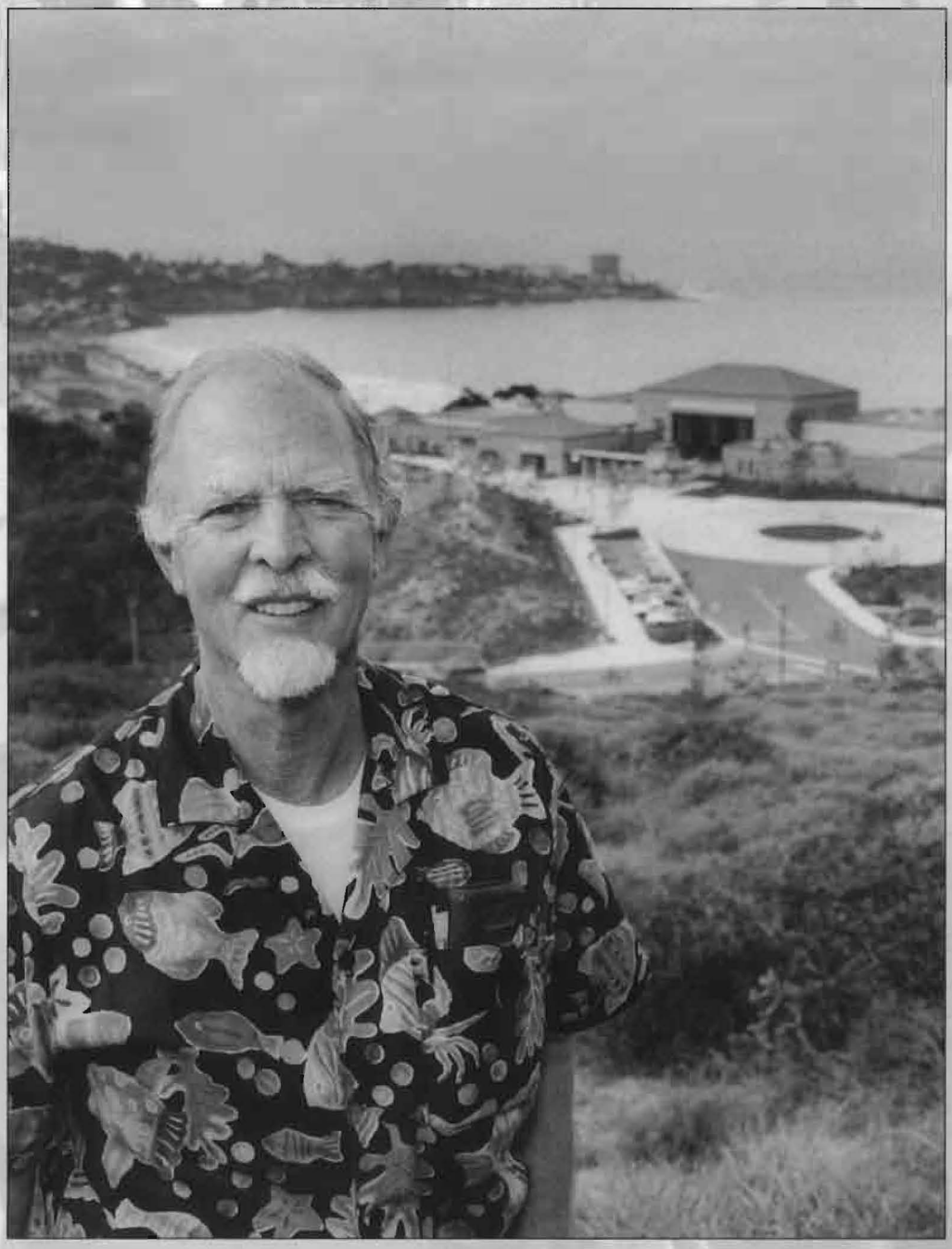
Members of the Scripps community are to be commended for facing this period of adversity by working together with enormous effort and great goodwill. We will succeed in our endeavors with their help and devotion to the institution.



Edward A. Frieman, Director
February 1993

Below. Dr. George G. Shor, Jr., on the upper part of the Scripps campus, with the Stephen Birch Aquarium-Museum in the background.

Photo page 7. Dr. Shor on the stern of R/V *Melville* using a sound-powered phone to call the bridge during launching of a seismic telemetry buoy.



D E D I C A T I O N

GEORGE G. SHOR, JR., came to Scripps because "they would actually pay me to do what I like to do: go to sea, set off explosions, and map the earth's crust." He did so for 25 years, going to sea an average of two months per year, aboard 15 different ships. George also served as a leader in almost every operation of the institution and its ships. Now professor emeritus of marine geophysics, his is a lifetime of service to Scripps.

Born in New York City in 1923, George came to California in 1940 to the California Institute of Technology in Pasadena, where he joined the Navy and earned a B.S. in engineering and an ensign's commission through the Navy V-12 program. He became a communications officer and deck officer on a Navy AKA operating in the Atlantic and Pacific. In 1946, he returned to CalTech, earning an M.S. and a Ph.D. in geophysics. During this interval, he also spent three years heading a seismic exploration crew looking for oil in Texas, and in 1950, married Betty, a CalTech 'PK' (professor's kid).

In 1953, he joined Scripps's Marine Physical Laboratory to work with Russ Raitt on seismic exploration at sea. Together and separately, he and Russ crisscrossed the Pacific and Indian oceans, shooting off underwater explosions and using hydrophones, both towed and on the bottom, to record seismic reflection and refraction data on seafloor structure. These data helped lead to the understanding of plate tectonics. George became known for crafting innovations in seagoing operations, usually practical and labor-saving, but occasionally odd, from pipe-bombs to balloons. He led many oceanographic expeditions through the 1970s.

Simultaneously, George located the site for the Mohole, a dramatic scientific proposal to drill to the earth's mantle, which after many years of planning was dashed by changing politics. He then served on the initial planning group that established JOIDES and the Deep Sea Drilling Project.

Meanwhile, back on the beach, George made administrative contributions to Scripps, ocean sciences, and the local community. In 1964, Director Roger Revelle asked him to chair and reorganize the Ocean Research Division. He also created and chaired the Geological Research Division, was associate director of MPL and of IMR, became the first program manager for the California Sea Grant Program, and initiated seagoing technician programs. During this time, from 1968 to 1992, George was an associate director of Scripps, concerned at various junctures with campus planning and development, marine operations, technical support, and most everything else. He was deeply involved in restoring the 'Old Scripps Building' and creating the new Stephen Birch Aquarium-Museum.

George delved into the details of the Scripps fleet, participating in the design, acquisition, modification, and outfitting of many oceanographic vessels (and proposed the names of three ships and designed the SIO flag). During the past 12 years, he headed Ship Operations and Marine Technical Support, seeing to it that Scripps's research fleet remained the most efficient in the world. He made major contributions to the University National Oceanographic Laboratory System, the organization that coordinates the U.S. academic fleet.

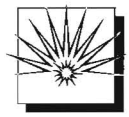
Closer to home, George and Betty are among the long-time residents of Scripps Estates, with George serving as the neighborhood association's president more than any other individual. Betty worked as a laboratory assistant to Carl Hubbs, went to sea on 12 expeditions, and authored several books, including one on Scripps's history. As well, they raised three children, one of whom has already beaten his father's record for seagoing.

George claims to be a national repository of useless information. In fact, he is the Scripps answer man. Perhaps no one knows more about Scripps buildings, facilities, roads, reserves, monies, and contracts and grants than George, and he is always enthusiastic to tell you what he knows, usually pacing as he talks.

George was appointed professor in 1969 and has authored 60 scientific papers. He is a fellow of the American Geophysical Union and the Geological Society of America.

Today, George pursues an interest in bamboo, not just growing 42 varieties at home, but participating with bamboo enthusiasts throughout the world in trading plants, helping botanical gardens, publishing a newsletter, and administering a bamboo society. You see, George never could just do something, he had to become part of it.

Dr. Michael J. Buckingham works on the acoustic receiver.



Acoustic Daylight: Imaging the Ocean with Ambient Noise

by Michael J. Buckingham

In the land of the blind the one-eyed man is king

Michael Apostolius, *Proverbia.*

SUNLIGHT PENETRATES only a few meters beneath the sea surface, leaving the ocean depths in pitch darkness. Sound, on the other hand, propagates easily through seawater and, under the right conditions, may be heard halfway around the world. The simple fact that the ocean is almost transparent to acoustic waves accounts for the success of sonar in numerous civil and military applications.

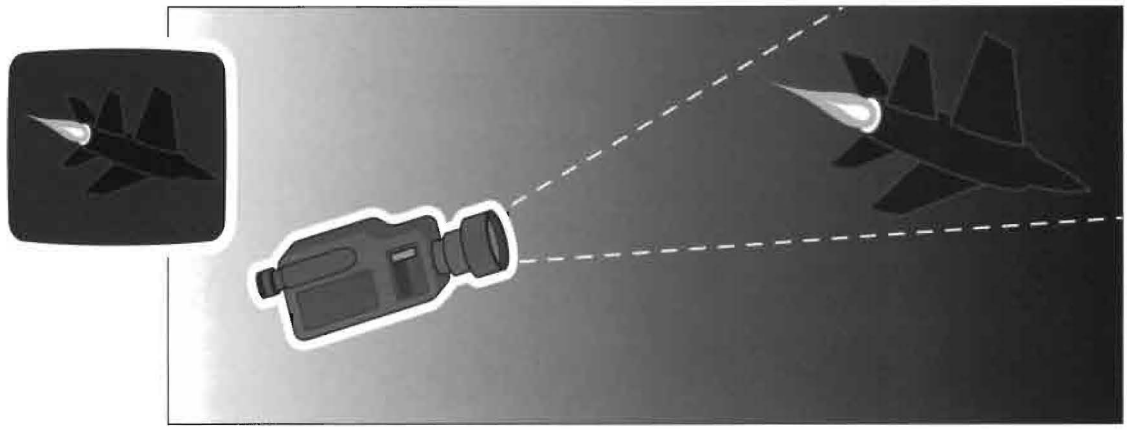
All sonar systems currently in service are either 'passive' or 'active'. A passive system is no more than a listening device that detects objects in the ocean (for example, submarines) by the sound that they emit, whereas an active sonar transmits an acoustic pulse and listens for returning echoes, from which the presence of one or more targets is inferred. Although both techniques are satisfactory under favorable conditions, the information they yield is in a sense primitive, consisting of complicated signals that can only be interpreted by a trained operator.

To appreciate the limitations of active and passive sonars, consider an optical analogy. Suppose that a jet aircraft is passing overhead in the night sky. Passive sonar is analogous to detecting the aircraft by the light radiated from its incandescent exhaust, whereas illuminating the aircraft with a searchlight is equivalent to the operation of an active sonar. In more usual circumstances, however, the aircraft would not be seen at night but in daylight, which is a form of visual observation that is neither active nor passive: it does not rely on light radiating from the aircraft, nor does it require an artificial source of illumination. Indeed, daylight detection has no acoustic analogue in current sonar systems, which quite literally operate as though the ocean were in total acoustic darkness.

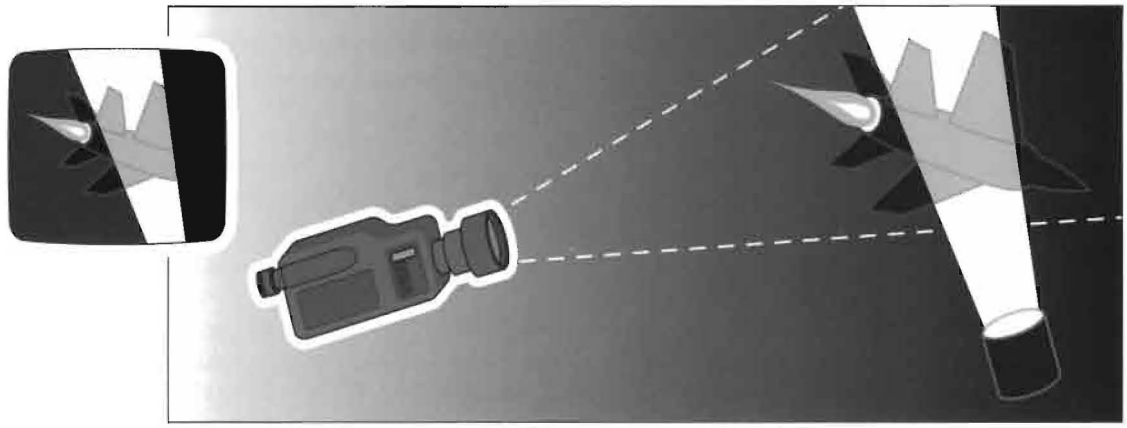
Daylight in the atmosphere consists of diffuse, incoherent light traveling randomly in all directions. Objects illuminated by daylight act as scattering agents, and the scattered radiation is the means by which the objects may be seen and photographed. If daylight can be used for recording pictures of objects in the atmosphere, it is natural to ask whether an acoustic analogue of daylight exists that could be used to form images of objects beneath the sea surface.

The ocean is a naturally noisy environment, mainly because of breaking surface waves, which create bubbles that 'ring', or resonate, for the first few milliseconds of their existence. These oscillating bubbles, although having short active lives, are extremely effective at producing sound. As the bubbles are distributed across the entire ocean surface, they fill the depths with sound waves, the so-called ambient noise field. Ambient noise in the ocean is an incoherent sound field consisting of acoustic energy traveling randomly in all directions and in this sense is the direct analogue of daylight in the atmosphere; that is to say, ambient noise is the 'acoustic daylight' of the ocean.

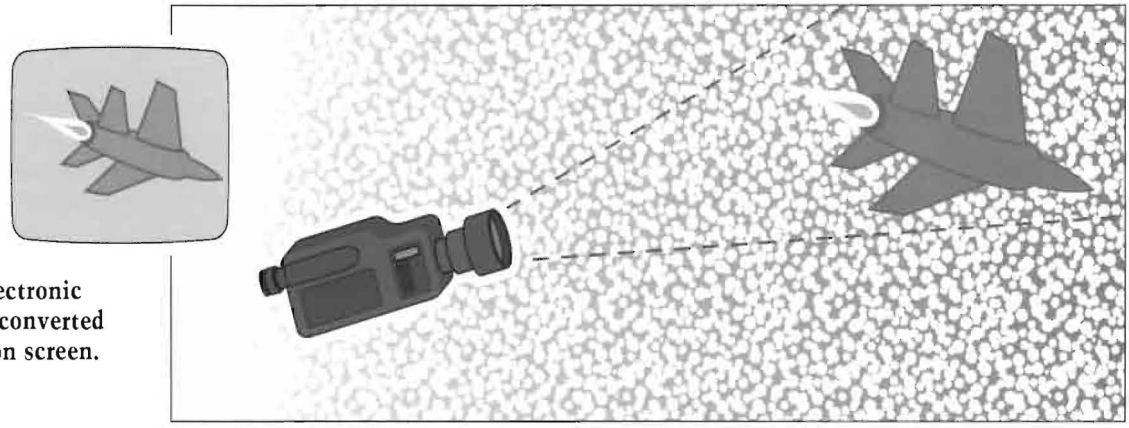
Passive sonar is somewhat analogous to observing an aircraft by the light radiated from its incandescent exhaust (although the analogy is limited, since images cannot be formed with passive acoustics).



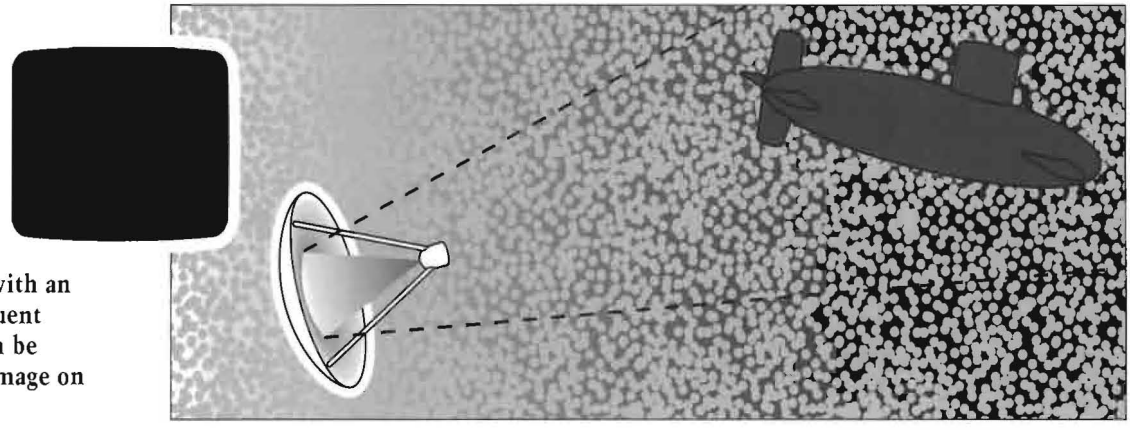
Observing an aircraft with a searchlight is somewhat equivalent to the operation of active sonar (although the analogy is limited, since images cannot be formed with active acoustics).



An aircraft illuminated by daylight (depicted by the white dots) scatters some of the incident radiation, which provides the 'signal' that is recorded by a video camera. After suitable electronic processing, this signal is converted to a picture on a television screen.



Ambient noise (depicted by grey dots) in the ocean is the analogue of daylight in the atmosphere. An object in the ocean scatters some of this 'acoustic daylight', thus providing an acoustic 'signal' which, with an acoustic lens and subsequent electronic processing, can be converted to a pictorial image on a television screen.



Graduate student Chad L. Epifanio and Dr. Buckingham examine the receiver after returning from sea.

To create pictorial images of objects in the ocean using ambient noise as the illumination, an acoustic lens is required for focusing the scattered sound, along with a visual display monitor. In principle, the lens could be a reflector, refractor, or phased array. The very first experiment on acoustic daylight imaging in the ocean was conducted recently by the Ocean Acoustics Group of the Marine Physical Laboratory (MPL). A simple parabolic reflector with a single hydrophone at the focus was deployed off Scripps Pier in about 7-m water. This system had a single look direction or 'beam', corresponding to just one pixel, or point, of an image. Although obviously limited in capability, this arrangement served as a good test of the acoustic daylight imaging concept: if it were to work for one pixel, then there would be good reason to believe that a complete image could be formed with a more advanced, multi-beam lens.

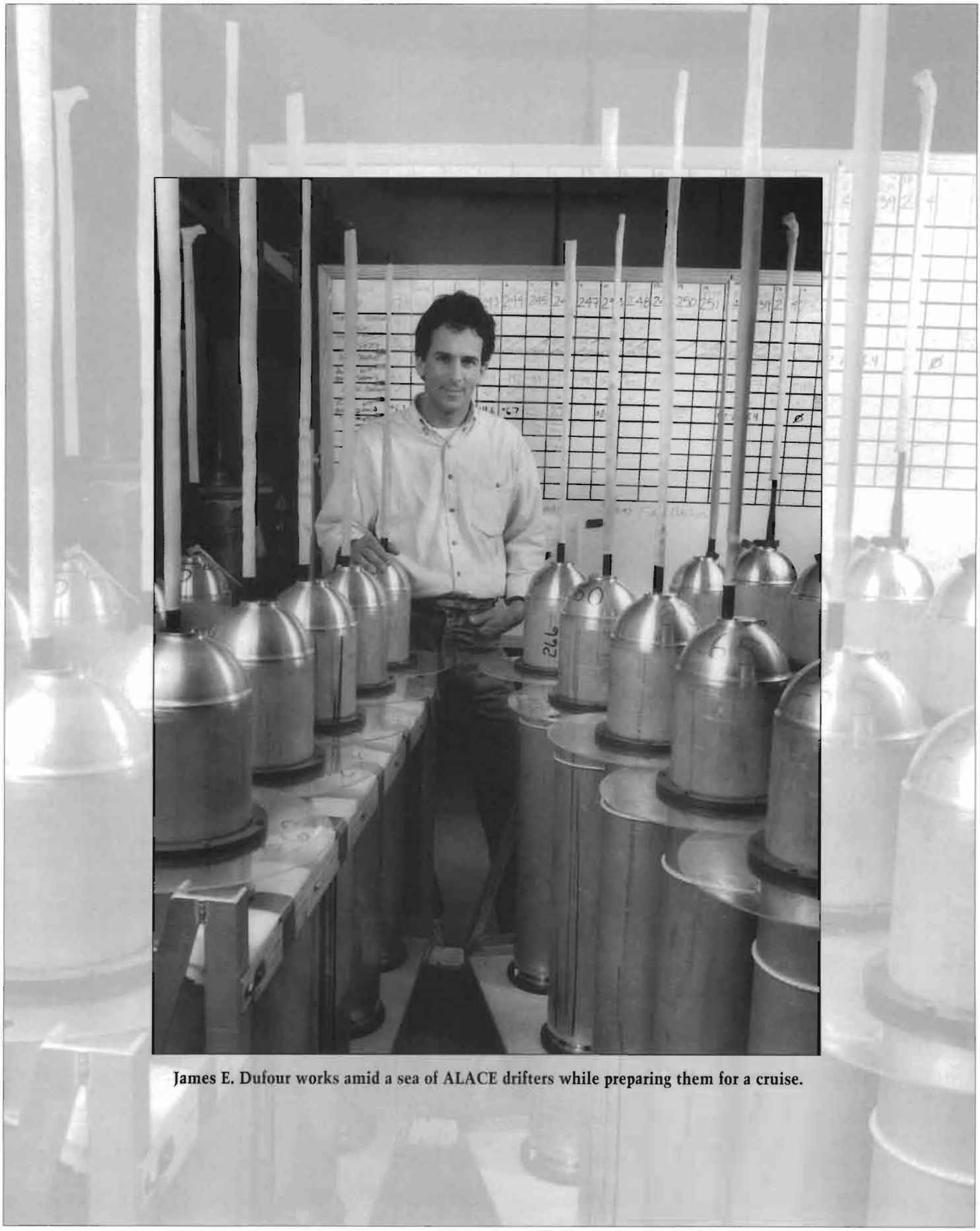
And indeed, the experiment was successful. When targets were placed in the beam of the reflector, the intensity of the noise at the receiver approximately doubled. Over a period of several days, it was repeatedly possible to 'see' the targets with ambient noise as the sole source of illumination. Moreover, the spectral structure of the signals indicates that the targets showed a frequency dependent reflectivity or albedo. In optical terms, the targets exhibited acoustic 'color'.

Looking to the future, our next step is to develop a multi-beam acoustic lens that will produce a recognizable pictorial image of one hundred or so pixels. Such a system is currently being designed and constructed at MPL. However, a static image is just the beginning. A frame rate that is fast enough to produce moving pictures appears feasible; and, with computer control, the acoustic 'color' of the object space could be converted into genuine visual color on the screen. Thus, the end product could be a color 'video' of the ocean depths, the origin of which is natural sound illumination rather than light. Although these acoustic daylight images would not match the pin-sharp clarity of human vision, because the wavelength of sea-born sound is so much greater than that of light, an improvement in acuity could be achieved by the application of image enhancement techniques.

Potential uses of the acoustic daylight imaging system include; surveillance of offshore structures, (notably oil drilling platforms); navigation of remotely operated vehicles (ROV's), especially under the Arctic ice cap; bottom prospecting for mineral deposits such as manganese nodules; detection and salvage of wrecks; monitoring of fish and marine mammal populations; to say nothing of many important naval applications. Acoustic daylight holds the promise of vision in the ocean, offering the prospect of remote oceanic exploration in a way that has never before been possible.

Suggested Reading:

Buckingham M. J., B. V. Berkhout, and S. A. L. Glegg. Imaging the ocean with ambient noise. *Nature*, v.356, March 26, 1992. pp.327-329.



James E. Dufour works amid a sea of ALACE drifters while preparing them for a cruise.

Deep Ocean Currents

by Russ E. Davis

FOR CENTURIES MARINERS have been aware of the large-scale surface currents of the ocean mainly because they are directly observable from the drift of floating objects. Today, satellite-tracked drifter buoys provide an important source of information about surface circulation. However subsurface currents, particularly those below 100 m or 200 m depth are difficult to observe.

Originally, oceanographers studying subsurface ocean circulation relied on the distribution of seawater density and other tracers like temperature, nutrients, or anthropogenic chemicals to infer ocean circulation. It was possible—using the dynamical approximations of a hydrostatic balance between pressure and density and a geostrophic balance between velocity and pressure—to infer the velocity difference between any pair of depth levels from density maps. However, absolute velocity had to be inferred from the distribution of tracers, patterns which are determined by the currents and by ocean mixing.

Within the last twenty-five years direct observation of deep currents has become feasible using moored current meters and acoustically located, neutrally buoyant floats. However, the moorings to support current meters or the acoustic equipment to track floats are expensive and require many days of dedicated research ship operation for deployment and recovery. Therefore, as powerful as these methods are, their use is still very limited.

A new ocean instrument developed in a joint project between Scripps and the Webb Research Corporation promises to disclose much about the deep ocean general circulation. The Autonomous Lagrangian Circulation Explorer (ALACE), which will be widely deployed as part of the World Ocean Circulation Experiment (WOCE), will facilitate mapping the absolute velocity at one mid-depth level over much of the globe. Coupled with extensive shipboard observation of density (to which WOCE will contribute substantially), we will be able to determine the global general circulation with unprecedented accuracy.

The ALACE is a neutrally buoyant float that drifts with the current at a preset depth down to 2,000 m. At predetermined intervals, typically a month in the WOCE deployments, ALACE rises to the surface where its radio signals are located by the ARGOS system aboard NOAA polar orbiting satellites. After a day on the surface, ALACE resubmerges to begin another cycle of current following. The float itself is a meter-long aluminum cylinder and 80-cm whip antenna that weighs 23 kg.

ALACE is cycled vertically by a battery-powered motor and hydraulic pump that moves oil from an internal reservoir into an external bladder. This increases the float's volume, making it more buoyant. ALACE then ascends in less than one hour. At the end of a surfacing period, oil is returned to

the internal reservoir and the float returns to its original volume to within a cubic centimeter, causing it to sink to its neutral buoyancy depth.

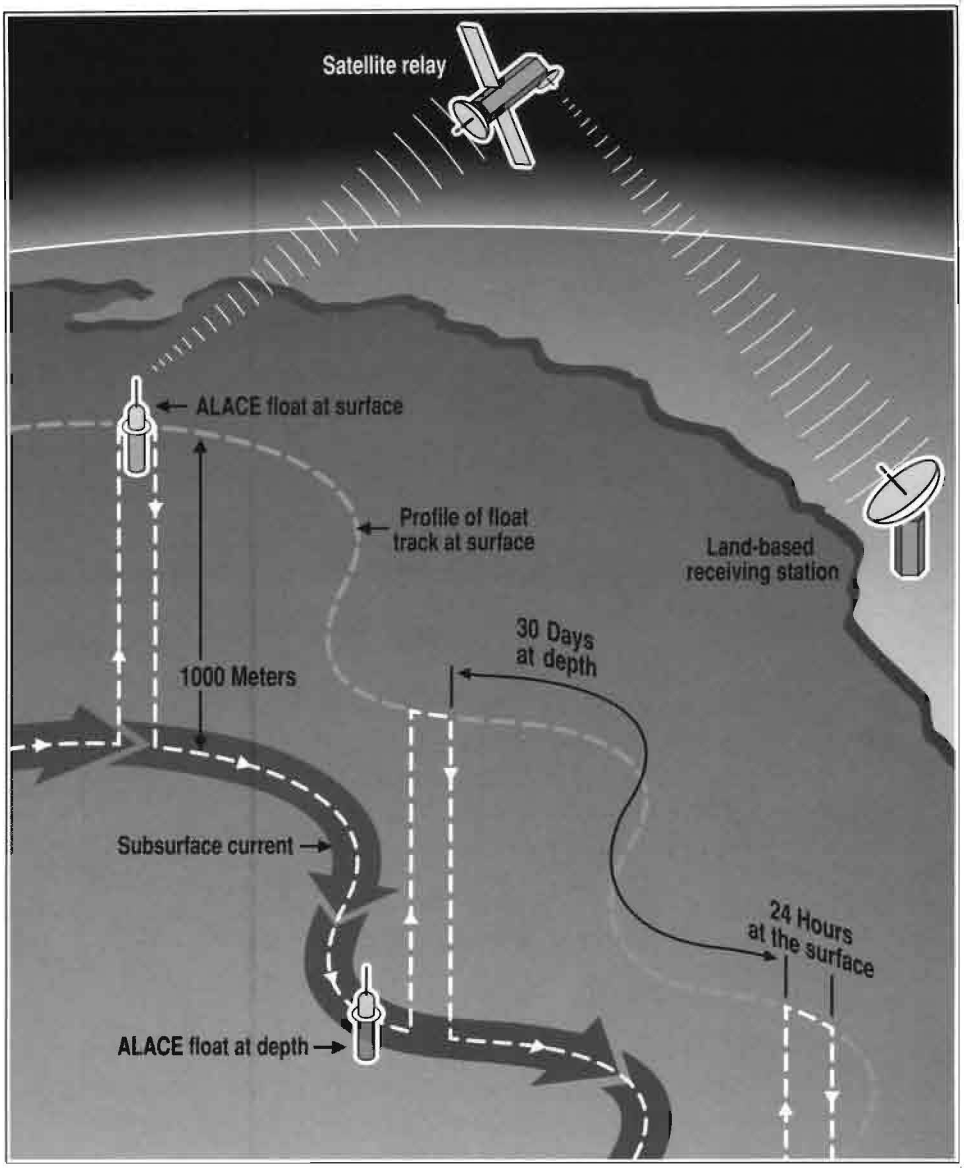
ALACE positions are known only when they surface, so they do not provide continuous velocity observations as can acoustically tracked floats. On the other hand, to determine the general circulation, which in most places is weak compared to eddy motions and other time variability, continuous velocity records are averaged over time spans of years. This velocity averaging is automatic as ALACEs are swept along by currents. Thus, while the subsurface trajectory is unknown, the information most important to measuring the general circulation is retained, and at a substantial saving in operational cost.

The efficiency of ALACE operation ultimately depends on their longevity. Operational life may be limited by corrosion or impact with ships or ice, but the maximum life is determined by the amount of energy stored in ALACE batteries. In normal operations about half this energy is used to cycle vertically while the other half is used to transmit information to ARGOS satellites. Sufficient energy is carried in the ALACEs used in WOCE to achieve 75 cycles over six years.

The first full-scale ALACE operation involved the release of ten floats in Drake Passage off the tip of South America in January 1990. Two floats malfunctioned early on (for a reason now corrected) and the remaining eight operated nominally, four exceeding their design (power-limited) life. During the first two years, two floats traversed the South Atlantic and entered the Indian Ocean, demonstrating the logistic advantage of floats that do not need moored acoustic equipment to be located.

Over 150 ALACEs have been deployed over wide areas of the tropical Pacific and South Pacific as part of WOCE. These are intended to be augmented by another 150 floats over the next two years. We believe that after these floats have been tracked for their lifetimes of 5 or 6 years, we can draw maps of large-scale current patterns near 1,000 m depth with an accuracy near 1 mm/s.

While their original purpose was observing large-scale currents, ALACE floats provide an important new platform for observing various ocean properties without the need for ships or moorings. ALACEs have been fitted with sensors to measure ocean temperature and salinity (from



Drawing shows how the ALACE drifter operates.

Photo page 15. Dufour records information obtained during testing.

which density can be computed) and programed to report profiles of one or both properties observed each time the floats ascend to the surface. The data are then compressed by an onboard microcomputer and transmitted through ARGOS.

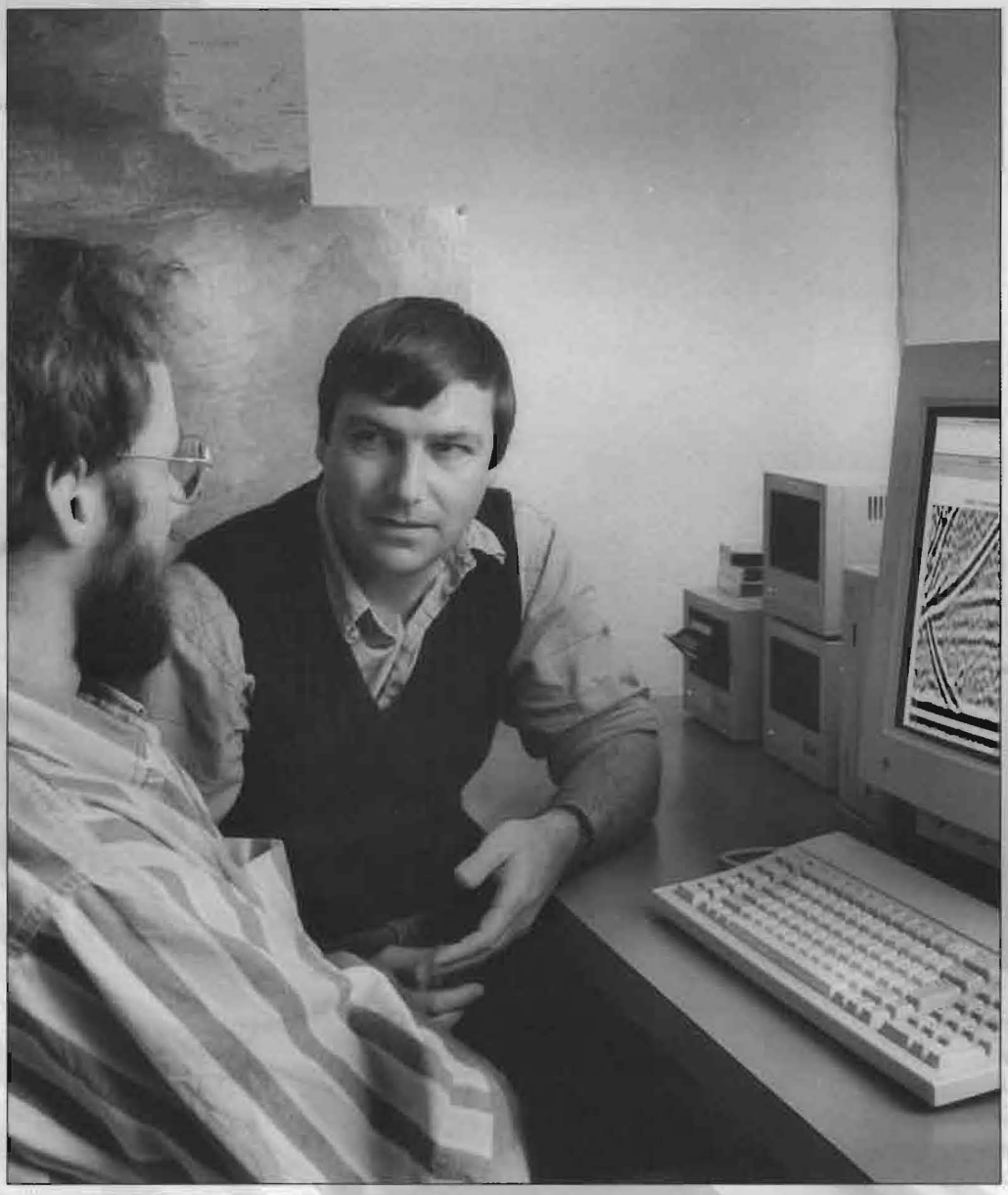
With the present configuration, ALACE reports more than 50 temperature and salinity profiles or about 75 temperature profiles to 1 km depth before battery power is exhausted. A modest increase in instrument size could double or triple this. Typical profiles contain values at 50 to 100 depths with temperature resolution of about 0.02°C and salinity resolutions of about 0.01 part per thousand. Temperature and depth accuracies are better than those achieved with expendable probes and the total cost per profile is comparable. Modern oceanographers now have new autonomous instruments that measure velocity, temperature, and salinity to help them elucidate subsurface currents.

Selected Reading:

Davis., R. E., C. D. Webb, L. A. Regier and J. Dufour. The autonomous Lagrangian circulation explorer (ALACE). *Journal of Atmospheric and Oceanic Technology*, v.9, no.3, 1992.

Reid, Joseph L. On the mid-depth circulation of the World Ocean. *Evolution of Physical Oceanography*, MIT, 1981.

Stommel, H. *A View of the Sea: A Discussion Between a Chief Engineer and an Oceanographer about the Machinery of the Ocean Circulation.* Princeton, New Jersey, Princeton University Press, c1987. 165p.



Drs. Peter M. Shearer and T. Guy Masters study computer images of global seismic data.

Global Mapping of Upper Mantle Discontinuities

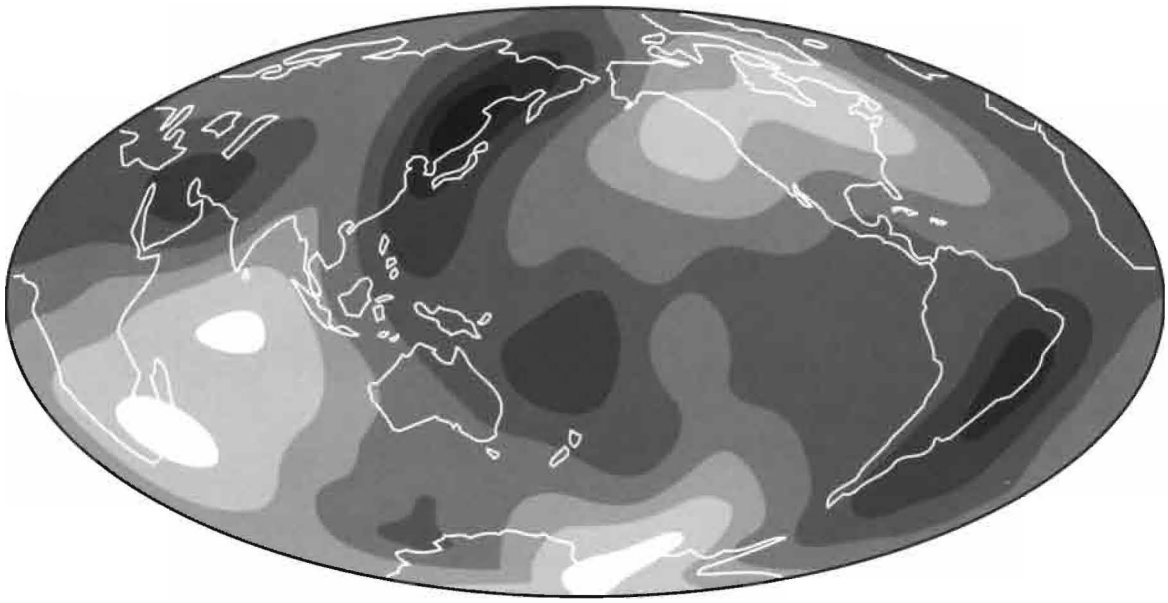
by Peter M. Shearer and T. Guy Masters

SOLVING THE PUZZLE of the composition of the earth's internal structure is one of today's scientific frontiers. New technology is providing valuable help to earth scientists in their studies. Earthquake records from seismic stations around the world are now available on compact disks and can be played back just as easily as an audio CD. With this rapid and easy access to a large number of global seismograms, scientists are developing innovative techniques for data analyses that may reveal new aspects of earth's internal structure. One such technique, developed at the Institute of Geophysics and Planetary Physics (IGPP), involves combining, or 'stacking', thousands of records from different earthquakes. This procedure reduces background noise and improves the visibility of weak seismic arrivals. Stacking methods, long used by reflection seismologists in oil exploration, have only recently been applied to global seismic data. For stacking techniques to function, the waveforms must be repeatable, or coherent, between different events. Fortunately, at long periods, stacking methods work well on global seismograms.

The images produced with these stacks reveal many weak global seismic arrivals that previously have not been seen. Most of these phases result from discontinuities (boundaries across which the internal character of the earth changes abruptly) in seismic velocities in the upper part of earth's mantle (the layer of earth between the crust and core). Although seismologists have known about upper mantle discontinuities at 410-km and 660-km depths for many years, the global extent of these features was unknown. The stacked images confirm the global nature of the 410-km and 660-km discontinuities, but indicate that the often postulated 220-km discontinuity is not a globally coherent feature. In addition, the stacks provide strong new evidence for a discontinuity near 520 km.

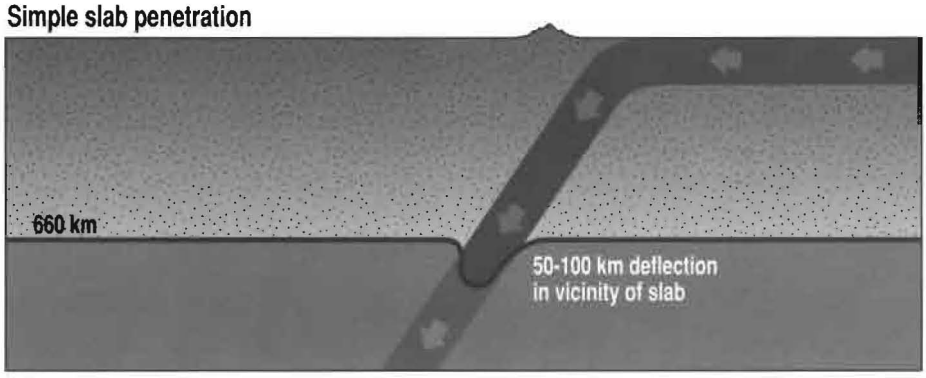
These boundaries are almost certainly the result of changes in the crystal structure (phase changes) of the minerals that make up the mantle, and result from the greatly increased pressure at depth. Experiments in high pressure mineral physics show that phase changes occur at different depths depending upon the temperature. Thus, seismic observations of the depths of upper mantle boundaries can provide a direct measurement of internal mantle temperatures. In addition, any variations in the depth of the boundaries resulting from discontinuity topography require the presence of lateral variations in mantle temperature.

Previous studies suggest that discontinuity depths may have some regional variations, but it has been difficult to evaluate the global significance of these differences. Our stacked images of long-period S-wave data

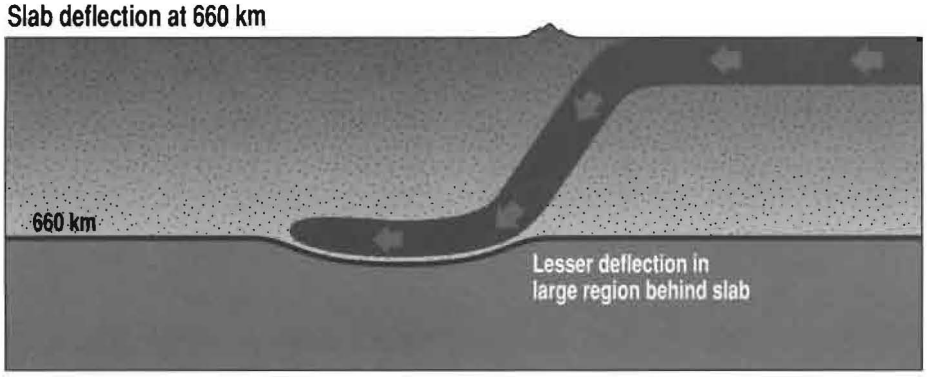


A global map of topography on earth's 660-km discontinuity. Depth variations are about 30 km, with the deeper regions (shown as dark gray and black) indicating colder areas within the mantle. The most clearly resolved feature is the large trough in the discontinuity behind the subduction zones in the northwest Pacific .

Simple slab penetration



Slab deflection at 660 km



The observed discontinuity topography favors models in which subducting slabs are deflected horizontally near 660 km to cause broad regional depressions in the discontinuity behind subduction zones. This argues against simple slab penetration into the lower mantle .

Drs. Shearer and Masters have used stacks of global seismic data, shown on the computer screen, to map depth variations in earth's internal discontinuities.

reveal a seismic arrival that comes from an underside reflection of upper mantle discontinuities. This arrival is ideally suited for mapping global variations in discontinuity depths because of the wide distribution of these reflection points.

Analyses of these reflections were used to produce the first global maps of topography on the 660-km discontinuity. These analyses indicate depth variations of 30 km, which are consistent with mantle temperature differences of 300°C to 600°C. Our most intriguing finding is that depressions in the 660-km discontinuity appear to be associated with subduction zones (regions on the earth where the surface plates are plunging down into the mantle). One might expect the 660-km discontinuity to be depressed in these areas because of the colder temperatures in the subducting slabs of material. However, the depressions observed are even larger than we would have predicted from simple models of slabs that pierce the middle of the mantle. The indication is that the slabs are deflected horizontally or broadened near 660 km to create a large area of cooler temperatures behind the subduction zones.

This finding touches on the controversial question of whether subducting slabs penetrate into the lower mantle or encounter resistance near 660 km that prevents convection throughout the entire mantle. This debate is far from over although our results, coupled with other studies of the seismic velocity structure near subduction zones, argue against simple models of unhindered slab penetration into the lower mantle.

Mantle temperature variations can also be mapped from three-dimensional imaging of velocity variations throughout the mantle. We are currently producing such images through analysis of thousands of long-period travel times. We plan to combine these results with the observations of mantle discontinuities to produce unified models of mantle velocity and temperature variations.

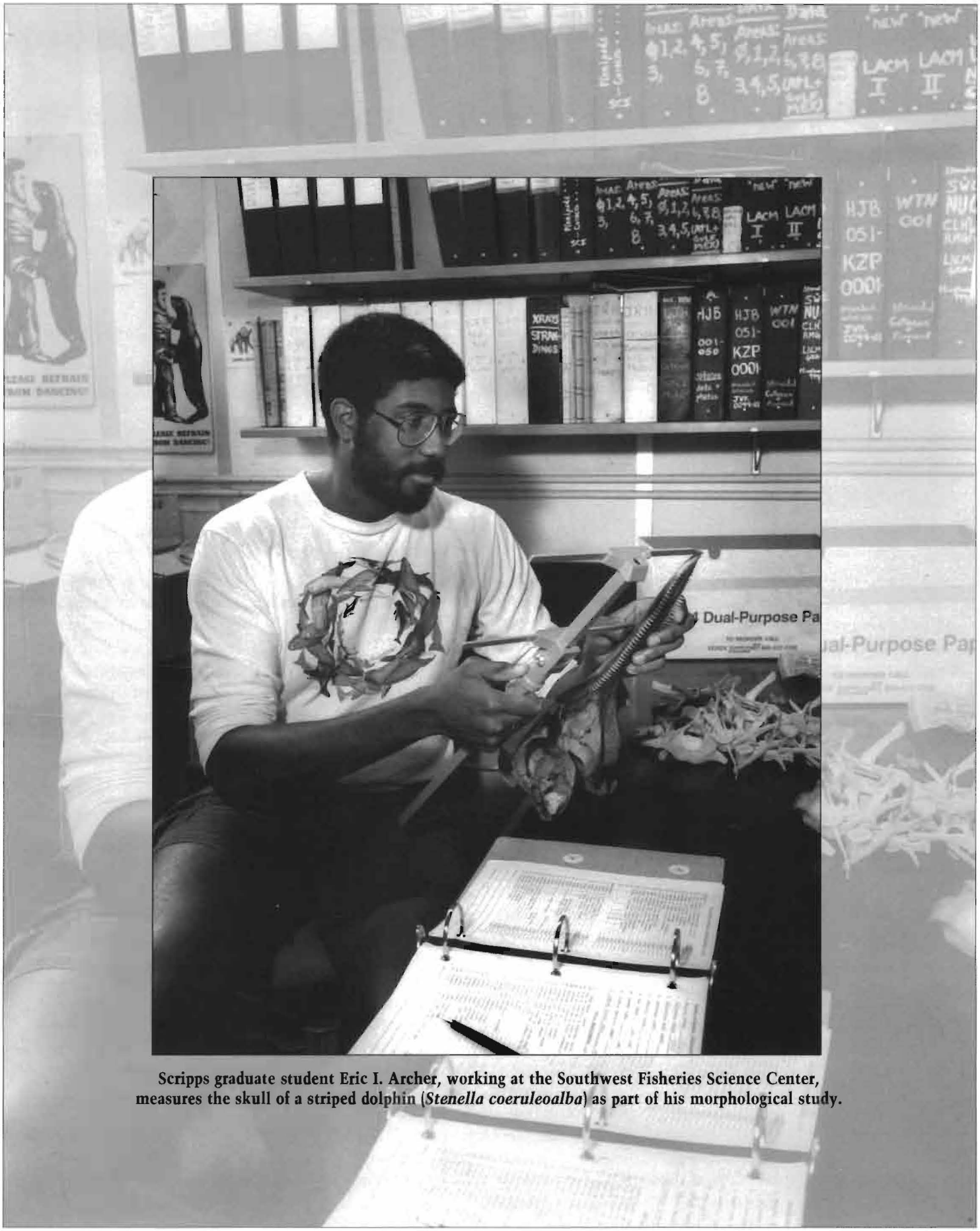
We will soon have substantially improved results because the quality and quantity of global seismic data are rapidly increasing, in large part because of the ongoing expansion of the Incorporated Research Institution for Seismology/International Deployment of Accelerometors network of seismographs operated by IGPP scientists.

Suggested Reading:

Shearer, P. M. Seismic imaging of upper-mantle structure with new evidence for a 520-km discontinuity. *Nature*, v.344, 1990. pp.121-126.

Shearer, P. Constraints on upper mantle discontinuities from observations of long-period reflected and converted phases. *Journal of Geophysical Research*, v.96, 1991. pp.18,147-18,182.

Shearer, P. and T. Guy Masters. Global mapping of topography on the 660-km discontinuity. *Nature*, v.355, 1992. pp.791-796.



Scripps graduate student Eric I. Archer, working at the Southwest Fisheries Science Center, measures the skull of a striped dolphin (*Stenella coeruleoalba*) as part of his morphological study.

Cooperative Studies with the Southwest Fisheries Science Center

RESEARCH SOMETIMES IS classified as basic, driven solely by scientific considerations, or applied, driven by some specific need of society. The close proximity of Scripps to the Southwest Fisheries Science Center (SWFSC) has provided the opportunity for many collaborative projects that have proven hybridization between the two approaches is not only possible but powerful. Compliance with the many federal management acts often requires SWFSC scientists (from National Marine Fisheries Service and the Inter-American Tropical Tuna Commission) to collect large amounts of population and environmental data; data which would be prohibitively expensive to collect for individual research projects. These data are available to Scripps scientists, often without restrictions. In exchange, Scripps scientists are often able to apply new or modified procedures from other disciplines to problems that are of interest to SWFSC scientists and to bring a broader oceanographic perspective to fisheries problems.

The cooperation of these two institutions has allowed thirteen Scripps students in 1991-1992 to conduct research on a wide variety of oceanographic problems under the combined guidance of SWFSC and Scripps scientists.

Many Scripps students are studying the biology and ecology of marine mammals in conjunction with SWFSC researchers. Drs. William F. Perrin and Andrew Dizon are supervising several students working on molecular systematics. These students are attempting to reconstruct the evolutionary history of certain cetaceans (whales, dolphins, and porpoises) by examining variations in DNA structure. A new development, the polymerase chain reaction (PCR), now allows scientists to replicate and examine characteristics of mitochondrial DNA from minute tissue samples collected from either living or dead animals. With PCR, scientists can generate large amounts of precisely copied genetic material in a very cost-effective way. They can then examine and compare differences and similarities in genetic material among species and also among various stocks of a given species, comparing hundreds of characteristics rather than the few visible traits available for traditional morphological studies (e.g. jawbones and teeth).

Graduate student Patricia E. Rosel adapted the molecular techniques in the Scripps laboratory of Dr. Margo G. Haygood, and subsequently introduced them to SWFSC, where they are applied by her and other Scripps graduate students. For example, Eric I. Archer is using PCR in a study of genetic distances between stocks of striped dolphin (*Stenella coeruleoalba*) populations in the Mediterranean, western Pacific, and eastern and western Atlantic oceans. Archer

will compare genetic data with morphological data from the ocean areas off Asia and Europe.

Studies on other populations are being conducted by Scripps graduate students Rosel, Richard G. LeDuc, and Angelica I. Garcia. In many cases, their genetic results support and strengthen the conclusions drawn from morphological comparisons. However, in some instances genetic classification conflicts with the current morphological classification leading to revision of the taxonomy of these species.

The federal Endangered Species Protection Act specifies that animals are to be managed to conserve species, or 'genetically isolated stocks' within species. Thus, the accurate determination of the degree of genetic similarity of populations has great practical importance, beyond scientists' inherent desire to understand relationships.

Other Scripps graduate students are working with field data, combining ecological research with management issues. Paul Wade is examining ways to improve the statistical analysis of survey data, and Debra Palka is developing improved population models for the rapidly declining harbor porpoise. Karin Forney, working with Dr. Jay Barlow in the SWFSC's Coastal Marine Mammal Program, is investigating relationships between cetacean distributions and oceanographic features along the California coast. Sue Moore, working with Drs. Douglas DeMaster of SWFSC and Paul Dayton, is studying patterns of distribution and abundance and migration routes of bowhead whales along the Arctic continental shelf.

Archer fits together the vertebrae of a striped dolphin.

Graduate student Michele Lyons is working with SWFSC's Dr. Paul Smith to explore the possibility of extracting biological information from a technique developed by physical oceanographers. The Acoustic Doppler Current Profiler (ADCP) was originally designed to measure currents by sending out a pulse of sound from the ship at a certain frequency. This sound is returned by particles suspended in the water. The frequency of sound returned depends upon the speed that the particles are being transported. Thus, the shift between outgoing and returning frequencies indicates the speed of the water. Also, the amount of sound reflected back is an index of the density of reflecting particles. Lyons is studying the theory that zooplankters are the dominant reflector. Thus, the ADCP return signal may be used as an index of the abundance and pattern of zooplankton biomass in the ocean, providing nearly instantaneous information on scales both too small and too large to be resolved by traditional zooplankton net tows.

Because ADCP data is collected by physical oceanographers routinely on many cruises, it represents an enormous amount of low-cost infor-

mation related directly to the ecology of the zooplankton, and indirectly to the ecology of the fish that prey upon them, much as the use of echo sounders by geologists provided biologists with information on the deep scattering layer.

Graduate student George Watters, working with Dr. Dayton at Scripps and Dr. Rick Deriso at SWFSC, is taking advantage of an experimental crab fishery around the sub-Antarctic islands to investigate an intriguing Antarctic mystery. The Cretaceous fossils are rich with crabs, and the crabs persist with no break across the Cretaceous-Tertiary boundary into the Eocene. At that point, Antarctic crabs become extinct, perhaps because of the Eocene cooling. Although crabs remain abundant around the sub-Antarctic Islands, they have never returned to the Antarctic continent. Given the prominence of crabs in the Arctic, this Antarctic pattern is unexplained. Watter's study of the population biology of a deep-water species of crab will be important for proper management, and it could provide a clearer perspective of this evolutionary question.

Collaborations such as these between Scripps and SWFSC not only broaden the scope of scientific expertise available to Scripps students, but expose them to the demands and challenges of resource management. The lines of communication established between university and federal researchers are slowly closing the artificial gap between basic and applied research.

Scripps graduate student Richard G. LeDuc loads an electrophoresis rig to determine the sequence of DNA samples from dolphins.

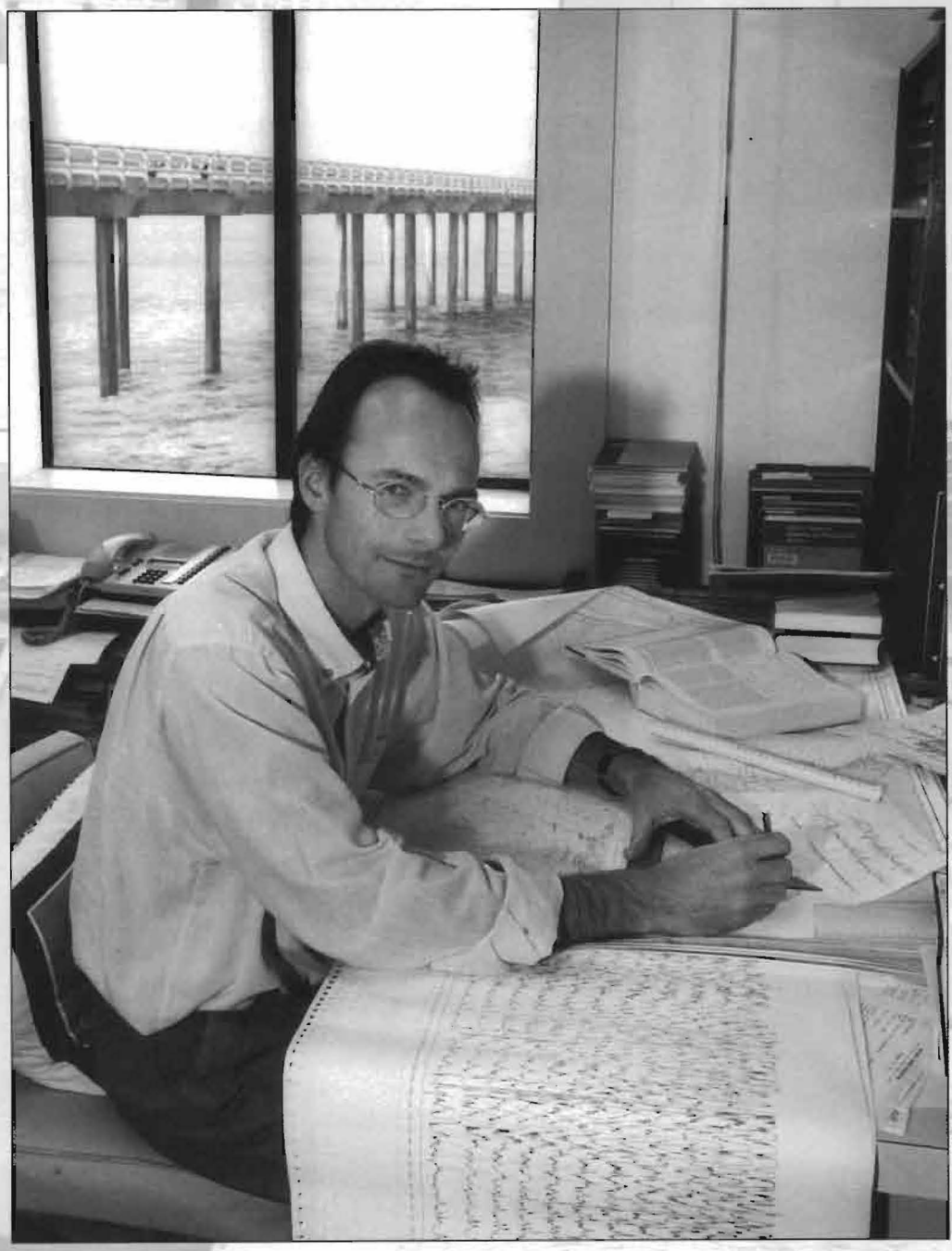
LeDuc and Dr. Andrew E. Dizon examine the sequence of DNA samples from northern right whale dolphins as part of a population study.

Suggested Reading:

Burnham, K. P., D. Anderson and J. Laake. Estimation of density from line transect sampling of biological populations. *Wildlife Monographs*, no.72, 1980. 202p.

Smith, Paul E., Mark D. Ohman and Laurence E. Eber. Analysis of patterns of distribution of zooplankton aggregations from an acoustic Doppler current profiler. *CalCOFI Report*, v.30, 1989. pp.88-103.

Dr. John L. Largier reviews charts and data from the western Agulhas Bank.



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

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

Physical Oceanography Research Division

SCIENTISTS IN THE Physical Oceanography Research Division (PORD) study problems in the physics of the ocean and marine meteorology. Investigators at PORD conduct observational studies of the large-scale circulation of the world's oceans, circulation over the continental shelf, in marginal seas and through straits, in estuaries and in the surf zone of open shorelines. They also examine the interaction between the ocean and the atmosphere, including large-scale forcing by wind and heat transfer; the absorption of gases into the very near-surface layer; the creation and maintenance of the surface mixed layer; and feedback mechanisms between the atmosphere, the ocean, and cloud formation. Theoretical studies include classical fluid dynamics problems and models of large-scale ocean circulation and the atmospheric marine boundary layer.

PORD scientists emphasize technological developments appropriate to physical measurements in the ocean. Recent innovations include a micro-structure profiling instrument called the Cartesian Diver, drifters (see Highlights section), an automated system for deploying expendable temperature probes from commercial vessels, high resolution bottom pressure sensors for deep ocean applications, and a towed version of the Acoustic Doppler Current Profiler (more commonly mounted through the hull of research vessels). These technological developments were necessitated by scientific questions, and have resulted in insights into ocean circulation.

Several research projects are reviewed including circulation and ecology of the western Agulhas Bank, vortex dynamics, and air-sea gas exchange. These reports indicate the diversity within PORD.

Air-Sea Gas Exchange

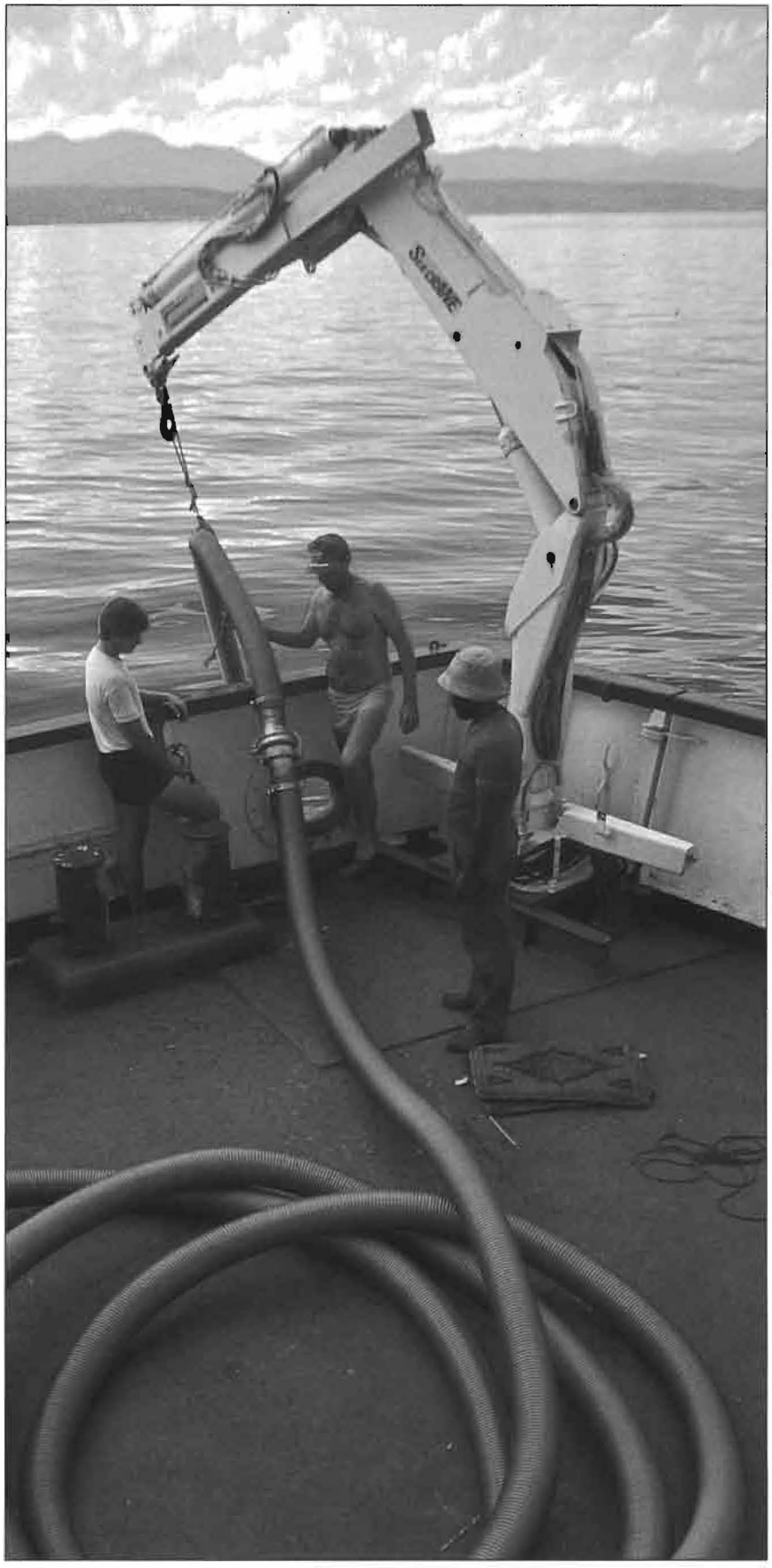
Transport of inert climate-relevant gases such as carbon dioxide and methane is controlled by a very thin boundary layer, only 30 to 300 microns (10^{-6} m) thick, at the top of the ocean. Although it is obvious that the transport is driven by the turbulent wind flow, details of the mechanisms still puzzle researchers. Scientists do not know either the intensity or the scale of turbulence in the vicinity of this layer, or how those parameters depend on wind speed and the short wind waves, or to what extent breaking waves and bubbles enhance gas transfer at high wind speeds.

Conventional measuring techniques are based on mass balance of the dissolved gas

tracer in the mixed layer. Thus they give only mean fluxes integrated over days to weeks, and cannot aid in elucidating the mechanisms of air-sea gas exchange.

Two major steps have been taken in the interdisciplinary research group of Dr. Bernd Jähne. The first, initiated a few years ago, is a technique that uses heat as a proxy tracer to measure the gas exchange rate locally and with a time resolution of a few minutes in the laboratory. This technique has been extended successfully to work in oceanic conditions at the Scripps Pier. The method has matured to the point that it can be used in the near future for open-ocean measurements from platforms and ships.

Another new technique is suitable for a detailed investigation of the mechanisms of air-sea gas transfer in wind/wave flumes. With this technique the flux of the gas across the boundary layer is converted into a flux of fluorescent dye by a fast chemical reaction in the vicinity of the water surface. Then the vertical concentration profile, with a resolution of about 10 microns, can be measured by stimulating fluorescence with a laser and taking high resolution images with an optical system including a charge-coupled device camera and a scanner that follows the water surface with the imaged sector. The technique works with very low concentrations. Less than one part per million of HCl gas in the gas space is sufficient to measure boundary layer profiles in a 10^{-5} molar fluorescein solution. Not only



J. L. Largier

Scientists aboard R/V *Meiring Naude* deploying a submersible pump for plankton sampling over the Agulhas Bank.

Deployment of a current-meter mooring from R/V *Meiring Naude* during the Agulhas Bank study.

J. L. Largier

can the transfer rate be determined instantaneously from the profiles but, for the first time, a direct insight into the transport processes is given.

Advanced digital image processing is the key to successful analyses of the images. Dr. Jähne's group has gained considerable experience in analysis of image sequences from short ocean wind waves, which resulted in the first systematic study of the two-dimensional wave number spectra of these wind waves. A fascinating interdisciplinary research area is unfolding, merging elements from physics, chemistry, and computer science.

Circulation and Ecology of the Western Agulhas Bank

The western Agulhas Bank occupies a unique position between the eastern boundary Benguela Current System (off the west coast of South Africa) and the western boundary Agulhas Current System. New observations from moorings off Quoin Point (34°45'S, 19°40'E) taken and analyzed by Dr. John L. Largier allow a fuller description of the dynamics of circulation and stratification, and the identification of three subregions.

The inner shelf is dominated by wind forcing, as in an eastern boundary upwelling system, whereas the outer shelf is dominated by oceanic forcing, as over western boundary shelves. The midshelf is characterized by strong vertical stratification that separates the near-surface oceanic water from near-bottom, upwelled Central Water. Current and temperature fluctuations within the different subregions are uncorrelated with each other, suggesting that the regions function independently.

The hydrodynamic coupling of the western Agulhas Bank with shelf regions to the east and to the west is an important mediator in the ecological connections between the Agulhas and Benguela shelf systems. The effects of circulation and stratification are clear as they impact on the availability of food and transport for the spawning anchovy *Engraulis capensis* on the western Agulhas Bank.

Greenland Sea Water Mass Variability

The water masses of the Greenland Sea form the source of North Atlantic Deep Water and the Western Boundary Undercurrent (a deep equatorward current that carries cold, saline water out of the polar regions and is an important component in oceanic heat transport). Deep vertical convection occurs in the Greenland Sea in some, but not all, winters. Dr. James H. Swift recently analyzed observations from 10 coordinated hydrographic cruises in the Greenland Sea, together with historical data. His analysis provides the most complete quantification of seasonal and interannual variability

in water masses available. Volumetric analyses of the water masses within the Greenland Sea indicate that the deep water has become less dense, warmer, saltier, and lower in oxygen since 1972. This is consistent with an absence of deep convective renewal at least during the last decade.

Interseasonal heat fluxes for the upper layers are reasonable for local exchanges. The deep water changes show gradual but steady influx of characteristics derived from the deep waters of the Arctic Ocean. In 1989 the deep Greenland Sea was near its warmest values yet recorded, and its density was relatively low, suggesting that conditions at the bottom have been ripe for deep overturn since then.

Vortex Dynamics

A new theory for the evolution of two-dimensional turbulence based entirely on vortex dynamics was developed by Drs. George S. Carnevale and William R. Young, in collaboration with several colleagues. The new scaling theory was compared successfully to high resolution simulations and verified by laboratory experiments. In addition to the scaling theory, the investigators introduced a model for decaying turbulence based on point vortices that can undergo mergers according to ad hoc rules—a model they believe will be a very useful tool in further explorations of two-dimensional turbulence. Recently, the theory has been extended to predict the size and strength of the end-state counter-rotating vortices of decaying two-dimensional turbulence as identified by long numerical simulations.

Drs. Rudolf C. Kloosterziel and Carnevale proved the formal stability of a family of vortices previously only known to be linearly stable. This is a major step forward because it opens the door for a proof of fully nonlinear stability. The vortices involved consist of an annulus of vorticity of one sign surrounding a circular patch of vorticity of the opposite sign. Through laboratory and numerical experiments, Drs. Carnevale and Kloosterziel discovered a new, stable vortex structure consisting of a triangular patch of vorticity surrounded by three semicircles of vorticity of the opposite sign. This is the only stable member of an infinite family of vortices consisting of vortex patches with the shapes of regular polygons surrounded by the appropriate number of semicircular vortices of the opposite sign.

Topographic effects on vortex propagation and production are also under investigation by Drs. Kloosterziel and Carnevale. In studies of dipoles, they have shown that the conditions for the reflection of dipoles from topographic slopes based on point vortex calculations compare well with laboratory dipoles and numerical simulations. This work may apply to the propagation of dipoles on continental shelves and in the magnetic confinement of neutral plasmas (where it is conjectured that dipoles can carry away significant quantities of energy). In collaboration with a colleague in Rome, they are investigating the effects of the orientation of topography to oncoming flow in the generation of vorticity over the topography.

Global El Niño-Southern Oscillation (ENSO) Waves in the Coupled Ocean-Atmosphere System

The El Niño-Southern Oscillation (ENSO), a climatic fluctuation involving ocean-atmospheric coupling conventionally thought to be limited in its scope to the Pacific basin, has been shown to have global implications in new research by Drs. Warren B. White and Stephen E. Pazan and a colleague. Using new mappings (approximately 620,000) of temperature-depth observations collected from 1979-1988, the scientists discovered global waves that propagate eastward along the equator in both the upper ocean and lower atmosphere and travel completely around the globe.

In this study, vertically averaged temperatures over the upper 400 m (TAV400) and surface wind stresses (SWS) represent variability in the upper ocean and lower atmosphere, respectively, over the entire globe. These data reveal that both TAV400 and zonal SWS are global, tropical phenomenon dominated by eastward traveling waves in the equatorial wave guide, requiring one wavelength and 3-4 years to travel completely around the globe.

The ability of equatorial ENSO waves in the ocean and the atmosphere to propagate eastward from one ocean basin to the next around the globe indicates that the dynamics involve ocean-atmosphere coupling. This coupling has the zonal SWS anomaly field instigating upwelling/downwelling in the TAV400 anomaly field on the equator. This, in turn, instigates convective activity in the overlying atmosphere that alters the overlying zonal SWS anomaly field. The latter allows the transition of the coupled wave from one ocean basin to the other. This coupling yields theoretical waves propagating eastward with speeds similar to those observed, (approximately 30 cm/sec). This indicates that the dynamics of the ENSO involve global considerations, with El Niño development off the west coast of South America considered a local manifestation (a very intense one) of a global equatorial wave.

Physiological Research Laboratory

SCIENTISTS IN THE Physiological Research Laboratory (PRL) conduct field and laboratory investigations of the biochemical, physiological, and behavioral adaptations of aquatic and terrestrial animals. They focus on the adaptations that enable marine organisms to survive, flourish, and specialize for extreme ranges of temperature, pressure, and salinity found in ocean habitats.

Dr. Edvard A. Hemmingsen and colleagues study gas bubble formation in liquids and organisms, concentrating on the mechanisms that induce spontaneous nucleation of bubbles at modest gas supersaturations. Solutions containing only dissolved substances or water are very stable and resist bubble formation, even at extremely high gas supersaturations. However, solid hydrophobic surfaces of many particulate matters suspended in aqueous liquids decrease the gas supersaturation tolerance, often dramatically. This phenomenon and its implications for bubble formation in decompression sickness is being studied.

Scientists in Dr. Jeffrey B. Graham's laboratory continue to focus on the physiological adaptations of fishes to their environment. They also work on other basic biological questions. Graduate fellow Peter A. Fields studies the thermal biology of local sea basses (*Paralabrax*) as a potential model for the marine biological effects of global temperature change. He compared the thermal selective behavior of basses. He and a colleague also investigated the thermal effects on oxygen binding of bass hemoglobin. In studies of tuna swimming carried out in Hawaii, graduate students Heidi Dewar and Keith E. Korsmeyer investigated aspects of tuna thermal biology, heart function, and metabolism using the Scripps water tunnel.

Dr. Gerald L. Kooyman's group investigates exercise and diving physiology in vertebrates and foraging behavior of aquatic vertebrates. With cooperation from Sea World of California and the Scripps Hydraulics Laboratory, a major study of cardiovascular responses of emperor penguins established

that these birds have about half the aerobic capacity and cardiovascular response as a domestic dog. Data analysis of previous years' investigations shows that these penguins are diving longer and deeper than any other avian divers. Although mainly a mid-water hunter, they commonly descend to the ocean bottom to hunt in the deep benthic environment.

Training of sea lions is in progress and will enable Dr. Kooyman's group to measure several cardiovascular variables during on-command dives. Studies on diving behavior are continuing on leatherback sea turtles in cooperation with scientists at the Southwest Fisheries Science Center and the National University of Mexico. Diving studies of Galapagos Island flightless cormorants are proceeding in collaboration with German scientists from the Max Planck Institut and the University of Bielefeld.

Dr. A. Aristides Yayanos is clarifying the role of pressure in the ecology and evolution of deep-sea organisms. Several years ago, he showed that in the cold, deep ocean, high pressure is a significant contributor to the vertical zonation of organisms.

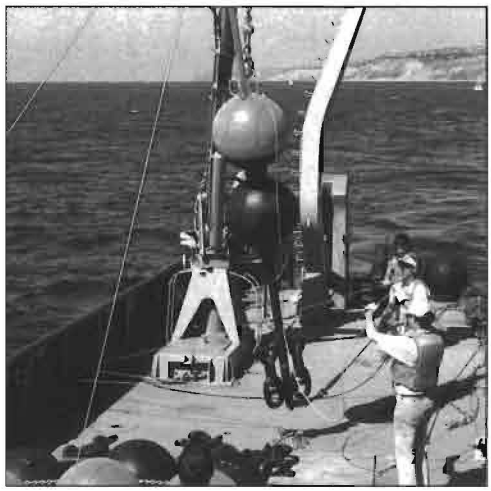
Lisel M. Winter attaches an instrument package to a sea lion before beginning dive training (page 29). Sea lion enters the boat for a dive training session offshore (top). Boat is lowered into water before training begins (bottom).

An analysis of data on bacteria from the deep, cold ocean (2°C), the Sulu Sea (9°C), and the Mediterranean Sea (13.5°C) has now led to a surprising hypothesis: pressure plays less and less of a role in zonation as the temperature of a high pressure environment increases. This hypothesis is now a focus of attention in studies with deep-sea bacteria.

A study on the photobiology of marine bacteria was initiated this year by Dr. Yayanos and Roger A. Chastain. They developed a method for detecting the amount of DNA-damaging sunlight penetrating the sea. They hope to use this technique to assess the temporal and spatial distribution of ultraviolet damage in the marine environment. Also, graduate student Frank J. Cynar completed his studies on the sources and sinks of methane, a greenhouse gas, in the coastal ocean off of southern California. He showed that methane in the upper ocean is derived from coastal seeps and from in situ production by bacteria.

Lisel M. Winter, Lisa Starke, and Dawn Reisinger train a rehabilitated sea lion to dive to a target in the open ocean as part of a diving physiology study (top). Researchers and sea lion return to Scripps after a training session (bottom).

Center for Coastal Studies



W. C. O'Reilly

SCIENTISTS AT THE Center for Coastal Studies (CCS) investigate the waves, tides, wind and density-driven circulation, and sediment transport in shallow seas, straits, estuaries, and open coastal areas. One CCS project is featured each year. This year, an ongoing study by Drs. William C. O'Reilly and Robert T. Guza of the wave climate in the Southern California Bight is described.

Surface gravity waves, often seen breaking on ocean beaches, drive processes that can damage coastal property, thin kelp beds, open and close coastal lagoons, and both build and erode the shoreline. Estimates of past and future wave conditions are used by researchers for many purposes, from surfing and recreational boating information to coastal engineering and planning. Despite the effect of waves on nearly every maritime and coastal activity in southern California, the wave climate in the Southern California Bight is not yet understood.

The Southern California Bight is one of the most geographically complicated coastal regions in the United States. The bight is bordered by Mexico to the south and Point Conception to the north and contains numerous offshore islands and shallow water banks. Wave energy from the open ocean can only reach the heavily populated and utilized southern California coastline by passing through gaps or 'windows' between the Channel Islands. Shoreward propagating waves are also significantly modified by the offshore banks and shoals; these features can act as lenses and focus (or diffuse) wave energy at coastal sites. As a result, wave conditions can be very different at locations separated by only a few kilometers. A prohibitively large number of in situ instruments would be required to continuously measure the wave field at all the sites of interest within the bight.

It is more practical for scientists to use computer models to estimate the wave field throughout the Southern California Bight when given the wave conditions off-

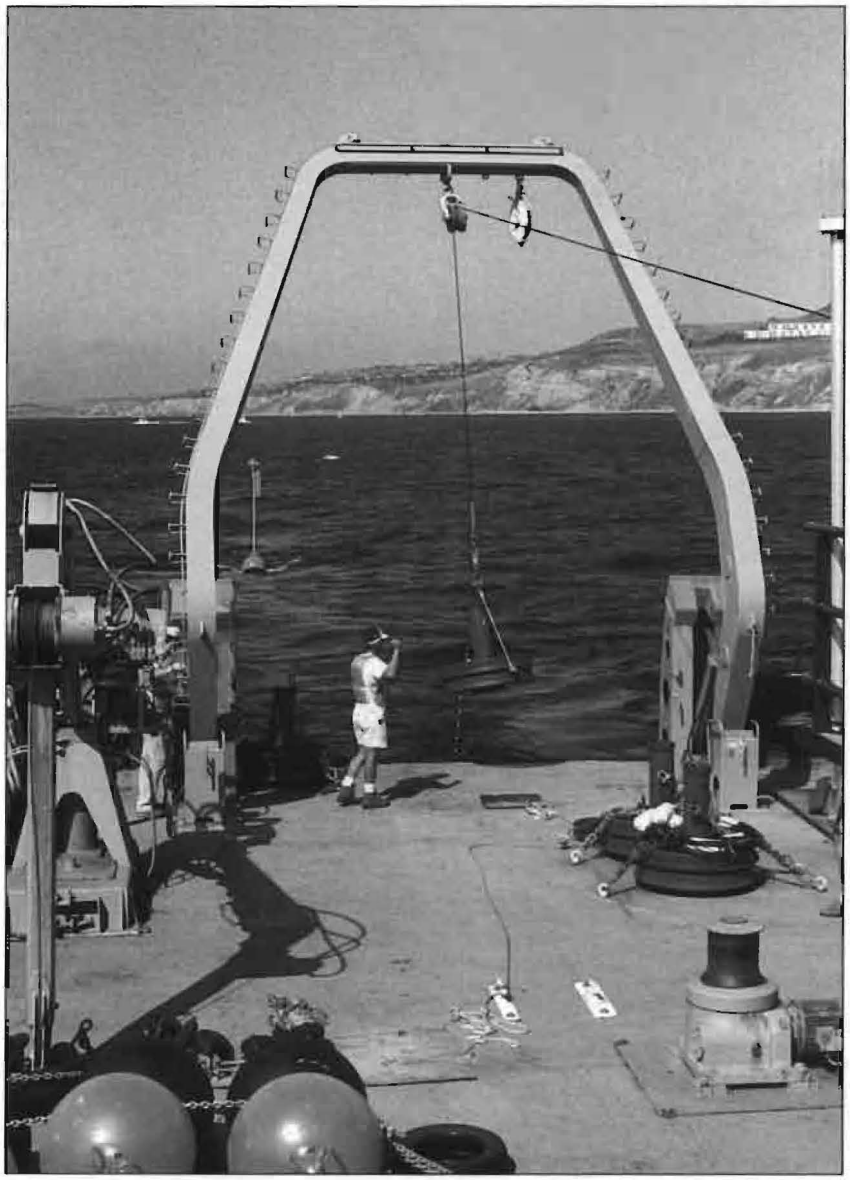
shore (seaward of the islands). More specifically, the amount of offshore wave energy at each period (the time between wave crests) and propagation direction (the directional spectrum of offshore wave energy) must be specified. Simulations on the San Diego Supercomputer of wave propagation in the bight show that coastal wave conditions can be very sensitive to details of the offshore directional spectrum. A small change in offshore wave direction can move a coastal site into (or out of) the 'wave shadow' cast by an island. Thus, very detailed estimates or measurements of the offshore spectrum may be required to accurately predict coastal wave conditions. Unfortunately, high-resolution directional measurements of offshore waves cannot be routinely obtained using traditional instrumentation.

Scientists involved in the Southern California Wave Experiment, funded by several organizations, are testing a novel method for making high-resolution estimates of the offshore directional spectrum from a collection of concurrent, sheltered wave measurements in the bight. The approach falls within a broad mathematical field known as inverse theory, which is utilized in many scientific disciplines. This is an inverse problem in that scientists are working backward, using sheltered wave measurements inside the bight to derive the directional properties of the source waves outside the bight. Estimates of the offshore spectrum can, in turn, be used in a numerical model to predict the wave field at uninstrumented coastal locations. Thus, researchers can effectively combine inverse and wave propagation modeling to interpolate between measurement sites.

The offshore wave conditions in southern California are typically dominated by waves arriving from different regions of the Pacific Ocean during different seasons. During the summer months, the majority of the wave energy in the bight arrives from Southern Hemisphere winter storms, or from tropical storms off the west coast of Mexico. During winter, North Pacific storms are the most common source of wave energy, and waves approach the bight from west-northwesterly directions. For this reason, the Southern California Wave Experiment consisted of two separate deployment periods

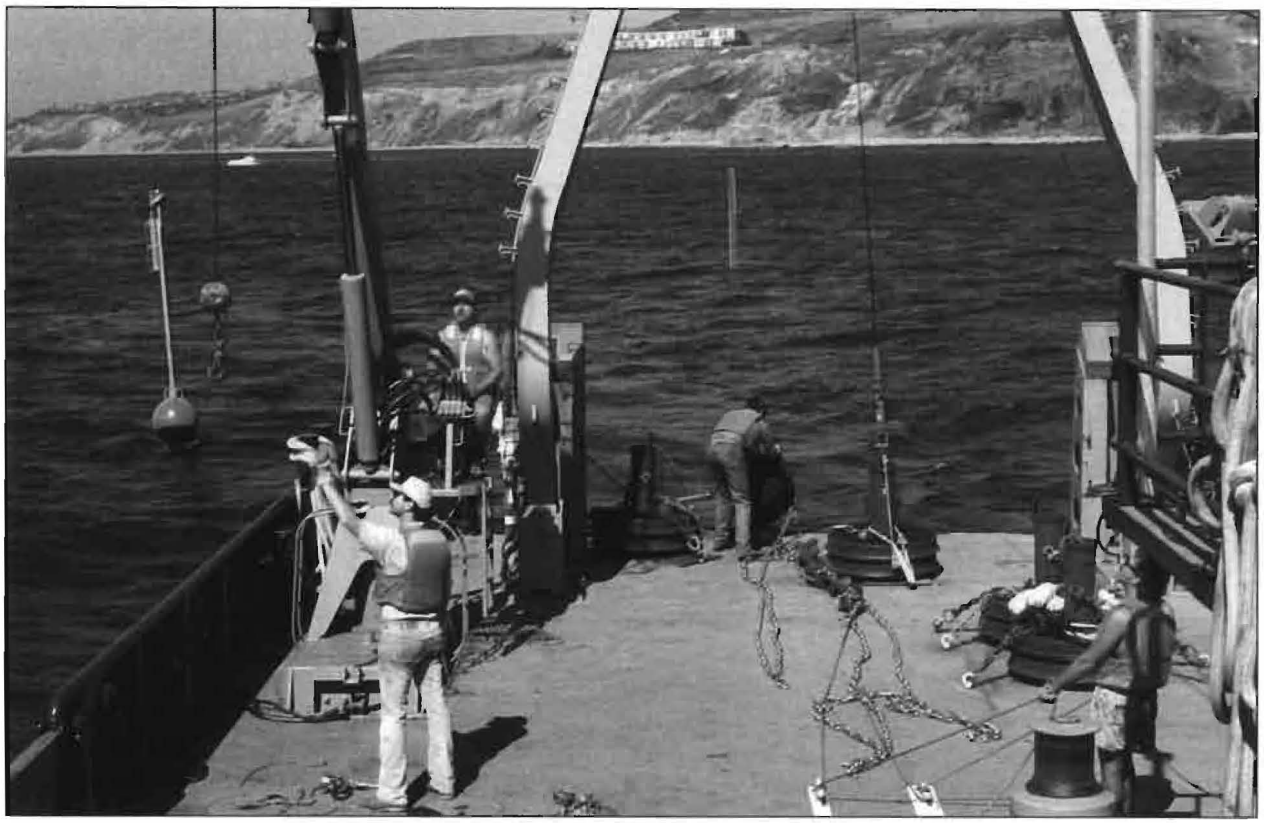
Dr. Reinhard E. Flick prepares surface buoys for deployment (page 32).

B. Walt Waldorf directs the deployment of the anchor-mounted wave gauge.



W. C. O'Reilly

Michael Kirk deploys subsurface marker buoy from fantail.



W. C. O'Reilly

tailored to examine waves from both the Southern Hemisphere and Northern Hemisphere.

Researchers measured waves with bottom mounted pressure sensors deployed from R/V *Robert Gordon Sproul* in water 30 m deep at 11 sheltered sites in the bight. Each self-contained instrument sampled the pressure every two seconds. If the instruments were placed so that the differences between measured wave energies were always the same regardless of the offshore wave direction, then the observations would not define the offshore directional spectrum. Therefore, the instrument deployment sites were selected using supercomputer simulations so that the wave energies would be very different from each other, with these differences strongly dependent on offshore wave directions. The deployed gauge networks were designed to obtain maximum information about the offshore directions of waves generated by storms in either the Southern Hemisphere or Northern Hemisphere.

In addition to these self-contained instruments used in forming the inverse estimates of the wave field within the bight, wave data at 12 additional locations were provided by the Scripps Coastal Data Information Program (CDIP, under the direction of Dr. Richard J. Seymour) and NOAA. Inverse model predictions of wave energy will be compared to the NOAA and CDIP data.

One interesting series of CDIP measurements was made using a directional buoy located 20 km west of Point Conception. Directional buoys are a common source of deep-water wave data; however, they are fundamentally low-resolution instruments. Researchers are determining whether these direct measurements of the offshore wave spectrum are sufficient to predict wave conditions in the bight. Preliminary comparisons indicate that an offshore directional buoy may be adequate for predictions at sites in the bight that are only moderately sheltered from North Pacific wave events. However, consistent with the supercomputer simulations, coastal locations with only a very narrow wave-window open to the North Pacific appear to require more sophisticated prediction schemes like the inverse method described above.

The number of instruments deployed along United States coastlines to monitor regional wave climates is expected to increase over the next decade. Results from the Southern California Wave Experiment will hopefully be useful in guiding both wave network design and integration of computer models with field measurements.

Climate Research Division

THE FOCUS OF the Climate Research Division (CRD) is climate variability on time scales of weeks to decades. Topics of special interest include long-range weather forecasting, El Niño and related phenomena, regional climate simulation and prediction, and climate change resulting from an enhanced greenhouse effect. CRD scientists analyze observational data and develop and use dynamical models of the atmosphere, the ocean, and other components of the climate system.

CRD scientists work both as individuals and as a team on several large multi-disciplinary projects. One of these is Sequoia 2000, a multicampus University of California effort sponsored mainly by Digital Research Corporation. In Sequoia 2000, scientists are constructing a statewide network for data transmission, together with hardware and software tools for dealing conveniently with large and heterogeneous data sets. This project will facilitate collaboration by allowing scientists to work with data from different sources, including model simulations and satellite and in situ observations. The Sequoia 2000 system will include capabilities for many types of analyses and visualization of data, including animation.

Dr. Tim P. Barnett will use the data storage and visualization capabilities of Sequoia 2000 daily to store and access gigabytes of data necessary for climate research. Dr. Barnett intends to investigate the results of 5,000-year simulations of the global ocean-atmosphere system with advanced computer models. His research will result in definition of the space and time scales of natural variability in the climate system. This information is vital to a new international effort to detect the first signs of greenhouse warming.

Dr. Barnett may also use the simulations to elucidate the physics responsible for 10-to-100-year variability in the climate system. He plans to determine if mankind is already affecting planetary climate, and the intrinsic limits to ultra-long-range prediction of weather and climate phenomena.

Water flowing out of the Yosemite Valley (page 35). Snowpack in the Sierra (below).

California Cooperative Snow Surveys, Department of Water Resources

Dr. Kyozo Ueyoshi is investigating winter temperature and precipitation extremes in the western United States with a mesoscale model. Using the winter extremes identified in global model outputs as external forcings of the mesoscale model, Dr. Ueyoshi is performing short-range simulations to develop a detailed climatic description of these winter extremes. He is also attempting to obtain a detailed climatic description of normal and drought conditions.

Using a perpetual wintertime atmospheric simulation, Drs. Shyh-Chin Chen, Daniel R. Cayan, and John O. Roads are examining the modeled inter-annual and inter-decadal temperature and precipitation variability over the United States west coast, particularly over California. In their preliminary analysis they find extensive dry spells and wet periods in this area. These local atmospheric hydrological and temperature extremes may be associated with slowly varying global circulation patterns in the model.

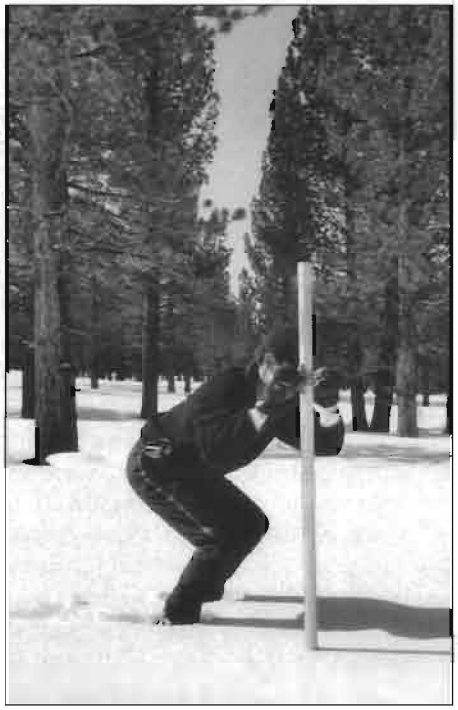
Drs. Nicholas E. Graham and Duane E. Waliser use remotely sensed data and a simple coupled surface energy balance model in their research. They showed, with surprising clarity, that clouds associated with organized tropical convection play an important role in constraining tropical sea-surface temperatures in regions of very warm surface temperatures, for example, the western Pacific. They are developing a parameterization of insolation anomalies associated with convective activity to incorporate into a coupled ocean-atmosphere model. Their study may induce a more realistic level of variability in simulated surface wind stress over the model tropical western Pacific.

Dr. Richard C. J. Somerville will use the Sequoia 2000 system to handle the observational data from two major field programs; the Atmospheric Radiation Measurement (ARM) Program (the flagship global change effort of the United States Department of Energy), and a multi-agency international air-sea program called Tropical Ocean Global Atmosphere - Coupled Ocean-Atmosphere Response Experiment (TOGA-COARE). The focus of ARM is on long-term (decadal) monitoring with emphasis on cloud-radiation interactions. The first two of several ARM sites are in Kansas and Oklahoma. TOGA-COARE will occur in the western tropical Pacific and last several months. Scientists with the program will explore the chief physical

mechanisms governing atmosphere-ocean interactions in the climatically crucial warm pool region.

Dr. Cayan and colleagues examined the influence of climate variability on runoff and snowpack in the western United States. They revealed three important points; first, the surface water balance components are moderately sensitive to natural fluctuations in temperature and precipitation. Second, surface variations are truly regional in scope, organized by North Pacific Ocean/western North America scale patterns in the atmospheric circulation. Finally, the resultant fluctuations in the timing and amount of runoff have significant impact on both the size and quality of water supply. A subtle but important aspect of climate influence is the tendency in recent decades for the peak runoff period in the Sierra Nevada and other western mountain watersheds to shift to earlier in the water year.

Dr. Dan Cayan studies weather maps as part of his research linking climate variability and surface hydrological fluctuations (snowpack and streamflow) over the western United States (above).



L. D. Ford

In the two photos at left, U.S. Forest Service hydrologist Doug McCarty takes a core sample at one of many 'snow courses' used to monitor the water content in the Sierra snow pack.

Geological Research Division

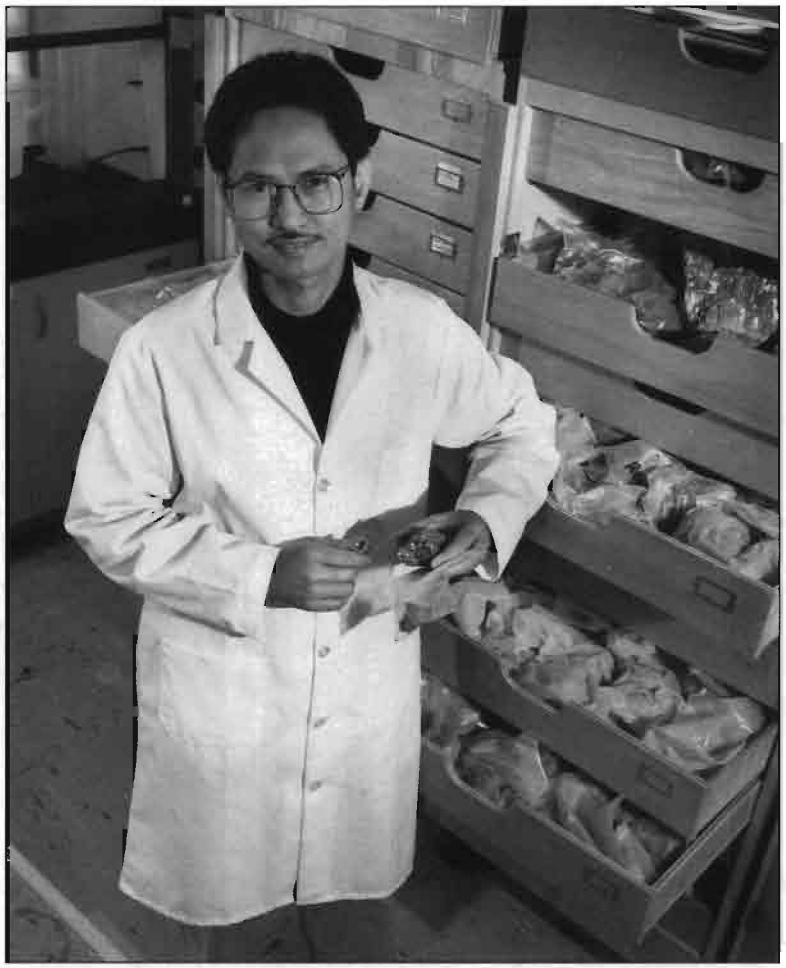
RESEARCH AT the Geological Research Division (GRD) covers many scientific disciplines. Scientist's studies range from mantle and crustal evolution, marine geology and geophysics, satellite altimetry, isotope geology and geochemistry, paleoceanography, marine geochemistry to atmospheric and planetary chemistry. This report covers a few selected research topics.

Dr. John G. Sclater and graduate student Dietmar R. Müeller study the relationship of geoid and topographic anomalies over fracture zones and the stability of hot spot traces in the Indian Ocean. Drs. Sclater and Seiichi Nagihara participated in a University of Texas cruise aboard R/V *Longhorn* to a salt stock and a salt canopy in 1,200-m deep water off the Texas gulf coast. They observed high heat-flow values over both structures. Particularly striking was an anomaly over the canopy in which the highest heat-flow values clearly delineated the position of the feeder stock.

In Dr. Wuchang Wei's studies of calcareous nannofossils and Cenozoic paleoceanography, he calibrated Pliocene-Pleistocene nannofossil species events with oxygen isotope stratigraphy on a global scale. This was done to determine their precise ages and their synchroneity or diachroneity in different oceans. Dr. Wei found that most species events occurred in interglacial periods rather than glacial periods. Based on the latest biochronological data and morphometric studies, he dated the upper Eocene microtektite/microkrystite layers (product of extraterrestrial impacts) distributed in the western Atlantic, Gulf of Mexico, Caribbean Sea, equatorial Pacific, and equatorial Indian Ocean. He showed that there is only one couplet of closely spaced microtektite layer and microkrystite layer with an age of about 38.3 million years. This is in contrast to popular belief that there are multiple layers of microtektites/microkrystites about 37.7 million years old.

Dr. Paterno R. Castillo prepares a rock sample from the Mt. Pinatubo volcano for analysis. First he selects the rock sample.

Then he crushes the sample (page 38).



Magmatism in the Western Pacific and its Margin

The possibility of predicting future volcanic eruptions is one of the goals of an arc volcanism project involving Dr. Paterno R. Castillo. He is investigating the geochemical and isotopic evolution of Mount Pinatubo in the northern Philippines. After ~600 years of inactivity, Mount Pinatubo erupted violently in June 1991. Volcanic rock samples from the recent eruption and from older lava flows were collected by Dr. Castillo during his visit to the volcano. He is analyzing these lavas to decipher if any systematic trend in their chemical and isotopic signature may elucidate magmatic processes along subduction zones and help predict future volcanic eruptions.

Dr. Castillo and graduate student Philip Janney are focusing on the subduction zone magmatism along the western Pacific margin. They analyzed lavas from the volcanically active Camiguin Island in south central Philippines. Camiguin lavas are unique for they erupted almost equidistant between two opposing subduction zones with respective volcanic arcs. Results of the investigation will elucidate Camiguin volcanic arc association and put constraints on the most probable reason for the unique tectonic setting of Camiguin Island.

Based on seafloor magnetic anomaly data it is thought that a large portion of the western Pacific is underlain by an oceanic crust that is about 145-210 million years or Ma in age (Jurassic). This crust is the remnant of the old Pacific Ocean that existed prior to the breakup of Gondwanaland about 100 Ma and is much larger than any of the modern oceans today. Thus, the western Pacific crust holds the key to understanding the history and evolution of the Pacific Basin. Several attempts in the last two decades to sample this crust were not successful because they failed to penetrate the thick sequence of volcanic lavas and volcaniclastic sediments overlying it. These volcanic products were derived from numerous atolls and guyots formed on the pre-existing Jurassic crust during the widespread volcanic event in the Cretaceous (65-145 Ma).

Dr. Castillo was on board during a recent leg of the Ocean Drilling Program (ODP) when the Jurassic crust in the western Pacific was penetrated and sampled in situ for the first time. Recently, Dr. Castillo and colleagues concluded their petrologic and isotopic investigation of the basaltic rocks drilled from the western Pacific oceanic crust. Their data show that the samples have an $^{40}Ar/^{39}Ar$ age of 166.8 +/- 4.5 Ma, and thus, these are the oldest rocks that have been discovered to date in the world's oceans. Their data demon-

Dr. Castillo weighs sample in his balance (below). Dr. Castillo and graduate student Philip E. Janney load a solution containing the sample onto an ion-exchange column to separate rubidium, strontium, and rare earth elements in a clean laboratory (right).

strate that the petrography, geochemistry, and isotopic composition of the oceanic crust accreted during the early history of the Pacific Basin are very similar to those of the modern lavas erupting presently along the East Pacific Rise. This study has increased our understanding of the history and evolution of the Pacific oceanic crust and of oceanic magmatism as a whole.

Dr. Castillo also participated in another ODP cruise when scientists investigated the origin, history, and evolution of the atolls and guyots in the western Pacific. During the cruise, the volcanic foundations of two atolls and volcaniclastic sediments from a third atoll were sampled. Dr. Castillo and Janney are investigating the petrography, mineralogy, bulk chemistry, and Sr, Nd, and Pb isotopic compositions of the volcanic rocks from the atolls. Based on the results, they will try to understand the petrogenetic relationship among the atolls, and the petrogenetic relationship between the Cretaceous atolls and the pre-existing Jurassic crust. They will also investigate possible sources in the mantle and mechanisms of formation of the magmas in the atolls, and put some constraints on the connection between the widespread Cretaceous volcanic event and mantle convection processes.

Ocean Productivity and Climate History

Dr. Wolfgang H. Berger's paleoceanography group focuses on paleoclimatic studies in the western equatorial Pacific, and on the history of storms in Santa Barbara Basin. In the western Pacific the group is interested in reconstructing the productivity history of the last million years. Their studies of benthic foraminifera show that productivity was increased by a factor of 1.5 to 2 in the area of the Ontong Java Plateau during glacial time.

Would such changes in paleoproductivity be recorded in diatom deposition? They found that high abundance and good preservation of diatoms go together, and vice versa. The correlation coefficient, r, between these two variables is 0.66, 0.90, 0.88, and 0.93, for the upper four cores of an ODP cruise.

Seventy taxa compose the diatom assemblage with *Azpeitia nodulifera* as the dominant member. This species exhibits significant size variations related to glacial and interglacial stages during the Pleistocene. Contrary to expectations, peaks of diatoms abundance coincide with interglacials, while barren samples show a greater probability of association with glacials. This is in direct conflict with the evidence from benthic foraminifera.

The stratigraphy of the phase relationship between the diatom abundance record and the $\delta^{18}O$ record of *Globigerinoides sacculifer* within the eccentricity window can be compared. On the whole, cycles

are in phase, with high sea level (interglacials) linked to high diatom abundance, and low sea level (glacials) to low abundance.

The factors responsible for reduced silica supply during glacials are not known, but possibilities include stripping of silica from the thermocline by deposition of opal in the margins, reduced supply of silica from the Atlantic caused by decreased flow of North Atlantic Deep Water, and faster growth of diatom species, with less silicification (leading to increased dissolution on the seafloor).

Also in Dr. Berger's group, Dr. Arndt Schimmelmann studies the isotopic composition of hydrogen in organic matter (such as kerogen and humic substances) isolated from marine sediments, fossil insect chitin, wood, cellulose, amino acids, and collagen. These organic materials contain exchangeable hydrogen atoms that can mask the isotopic signature of non-exchangeable hydrogen in measurements of total hydrogen. A new technique controls exchangeable hydrogen via isotopical equilibration and opens possibilities for studies of paleoclimates and paleoenvironments.

Cosmogenic Isotopes

The nutrient pathways in the surface ocean waters are complex, and various approaches are used to decipher them. To measure nitrate pathways ^{15}N labeling has been used, and artificial ^{32}P has been used to study certain biological pathways of phosphorus.

Dr. Devendra Lal's group advanced the study of phosphorus biodynamics by using cosmogenic nuclides ^{32}P and ^{33}P with half-lives 14.3 days and 25.3 days, respectively. They measure the specific activities of ^{32}P (primarily) in all the phosphorus pools (dissolved inorganic [DIP], dissolved organic [DOP] and particulate phosphorus [POP]). Using special chemical and radiochemical methods developed to measure the ^{32}P activities in large amounts of sea water, ~1,000-3,000 liters. The differences between these activities yield model ages of (7- ≥ 40) days for the mean residence time of phosphorus in these pools. No measurable ^{32}P activity was found in the DOP, indicating that the DOP pool exchanged phosphorus very slowly with the DIP and the POP pools, on time scales >40 days. This is not unexpected because nitrate is the limiting nutrient in sea water. Dr. Lal and graduate student Tongsup Lee were successful in their attempt to clarify the interrelationships between carbon export and nutrient biodynamics (nutrient exchange between the pools).

Soils are enigmatic because they are chemically 'open' systems. No direct measurements of soil-erosion or soil-formation rates have been made as yet. Approximate estimates have however been made either on the basis of geological evidence, or using the U-trend dating method. Approximate soil ages have been obtained from a determination of the integrated column inventories of cosmogenic ^{10}Be. Dr. Lal and colleagues have developed a method based on the $^{10}Be/^{9}Be$ ratio in in situ formed authigenic minerals. They tested the model for the incorporation of the radionuclide, ^{10}Be, and stable isotope, ^{9}Be, in soil minerals. This model predicts the highest $^{10}Be/^{9}Be$ ratios in a soil profile at the soil-rock interface, the layer marking the advancing of the weathering front of the soil profile. Experiments carried out on six residual soil profiles from arid and semi-arid regions support the model. They yield soil formation rates of (3-10) x 10^{-5} cm · yr^{-1}, consistent with geological evidence.

They also developed a new technique to gauge soil erosion rate by measuring in situ cosmogenic ^{14}C in a quartz vein in the soil profile in Reston, Va. The results yield a value of (1.1 ± 0.2) x 10^{-5} cm · yr^{-1} for the rate of erosion of the soil. This method seems to be applicable, even in cases when no quartz veins are present. They hope that large size rock pieces left unweathered in the soil profile can be used to determine soil erosion rates.

Micropaleontological Reference Center

Scripps is adding a new collection—the Micropaleontological Reference Collection. The Scripps center is one of eight Micropaleontological Reference Centers (MRCs) established in four countries to preserve material from stratigraphic intervals from the deep-sea sediment sequences recovered by the Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP). Scripps Institution of Oceanography now houses the U.S. West Coast Micropaleontological Reference Center.

These centers, established over the past two decades, have recovered an enormous wealth of deep-sea material from the coring operations of the DSDP and the ODP. This material provides scientists with new biostratigraphic information from ocean basins around the world, and may gradually be sampled out of existence. The collections contain specimens from four fossil groups—foraminifers, calcareous nannofossils, radiolarians, and diatoms—selected from samples obtained by DSDP and ODP. Samples have been prepared from DSDP Legs 1-96, divided into eight identical splits and distributed to each center.

Researchers visiting these centers may examine the quality of preservation and the richness of a large number of microfossils thus allowing them to plan more carefully their own requests for ODP or DSDP deep-sea samples. They also may compare actual, prepared faunas and floras (equivalent to type material) with figures and descriptions published in *Deep Sea Drilling Project Initial Reports* or *Ocean Drilling Project Proceedings* volumes, and with their own material. In addition to the fossil collection, the center will include a library containing the DSDP and ODP Initial and Scientific Proceedings Reports, and a vast collection of radiolarian literature.

Marine Biology Research Division

SCIENTISTS IN the Marine Biology Research Division investigate the biochemistry, physiology, and ecology of marine bacteria, animals, and plants. Their studies include the circulatory systems in invertebrates, the molecular genetics of pressure adaption in deep-sea bacteria, and the microbial loop in oceanic food web dynamics.

Dr. Farooq Azam's group investigates the roles of bacteria and viruses in the oceanic carbon cycle. Graduate student David C. Smith discovered that particle-attached bacteria rapidly solubilize sinking particles via hydrolytic enzymes, thus providing a biochemical mechanism for large-scale transfer of particulate into dissolved organic matter. Graduate student Grieg F. Steward developed a method to directly measure virus production in the ocean. It was found that viruses' attack on bacteria is spatially and temporally episodic in the open ocean but more persistent inshore. This may affect cross-shelf exchange of carbon fluxes in the ocean.

Scientists in Dr. Douglas H. Bartlett's laboratory study molecular aspects of the adaptation of deep-sea bacteria to the high pressures of the abyssal ocean. To facilitate the introduction of recombinant DNA into the deep-sea bacterium *Photobacterium* SS9, graduate student Ellen Chi cloned the *recA* gene, and constructed SS9 *recA* mutants. Graduate student Timothy J. Welch discovered that elevated pressure induces the production of heat shock proteins as well as certain unique 'pressure stress proteins' in *Escherichia coli*.

Graduate students Gabriela M. Tobal and Lakshmi N. Chilukuri in Dr. Bartlett's group study how enzymes from deep-sea bacteria function at high pressure. Laboratory researchers developed culturing techniques that improve the growth yields of the barophilic bacteria *Shewanella*, which will make protein biochemistry of these extremophiles feasible. Sequence analyses of the enzymes malate dehydrogenase and DNA gyrase are currently under way.

Dr. Horst Felbeck's group concentrates on the biochemistry and molecular biology of symbioses between chemoautotrophic bacteria and marine invertebrates. They made two major expeditions to the hydrothermal vent area at 13°N. Graduate student Ute Hentschel investigates the ability of symbiotic bacteria to utilize nitrate as a replacement for oxygen in respiration. She found this phenomenon in tubeworms from deep-sea vent areas as well as in shallow-living bivalves. Because the tubeworms lack a digestive system, all nutrition must be provided by their symbionts. Therefore, the continued characterization of the transfer of organic molecules between purified symbiotic bacteria and their host is under investigation.

Researchers in Dr. Margo G. Haygood's laboratory focus on symbioses between fishes and luminous bacteria. Graduate student Connie J. Wolfe discovered that the unculturable bacterial light organ symbiont of the Caribbean flashlight fish has only a single copy of the ribosomal RNA operon, instead of the eight to ten copies normally found in luminous bacteria. A reduced rRNA copy number also occurs in obligate pathogens. This suggests that the flashlight fish symbionts are obligate symbionts of the light organ and highly adapted to the slow growth conditions found there. Working with Dr. Daniel L. Distel, Wolfe sequenced 16S rRNA genes from the luminous symbionts of several flashlight fishes and deep-sea anglerfishes. Anglerfishes and flashlight fishes each have a distinct group of symbionts. Although none of these bacteria can be cultivated in the laboratory, they have found, by gene amplification and direct sequencing, that these luminous bacteria are not closely related to any known forms.

Dr. Bradley M. Tebo, in radiation lab, places filter into filter manifold to collect metal precipitates formed by marine bacteria containing radiotracers (page 42, and above).

Many marine bacteria produce siderophores (low molecular weight iron-binding compounds) which could be important contributors to organic complexation of iron in seawater. Scientists in the Haygood laboratory worked with colleagues and found that planktonic marine bacteria produced siderophores. One strain, a *Vibrio* sp. produced aerobactin, a siderophore not previously known for vibrios or any planktonic marine bacteria.

Dr. Bradley M. Tebo investigates the role of bacteria in the biogeochemical cycling of metals in the environment and their potential to immobilize, precipitate and detoxify metals (as in bioremediation). Graduate student Kevin W. Mandernack investigated the biogeochemical cycling of manganese (Mn) in hydrothermal vent environments. He is using stable oxygen isotopes of Mn oxide minerals to discover the biological or chemical origins of Mn deposits. He demonstrated the importance of bacteria in Mn cycling in hydrothermal vent environments and established the usefulness of oxygen isotopic measurements for unravelling mechanisms of Mn oxidation. Graduate student Yoon Lee is examining the potential for bacteria to oxidize cobalt (Co) and mediate the biogeochemical cycle of Co

in different marine environments. He demonstrated that some bacteria are capable of oxidizing Co, even at the low concentrations found in seawater.

Also, in Dr. Tebo's laboratory, graduate students Lorraine G. van Waasbergen and Ron Caspi are using molecular biological approaches to investigate the mechanisms of Mn oxidation by pure cultures of bacteria. Van Waasbergen focuses on a marine bacterium whose dormant spores bind and precipitate a variety of metals (zinc, cadmium, Co) in addition to oxidizing Mn. She is isolating the genes involved in Mn oxidation to identify the gene(s) coding for the spore's Mn oxidizing factor. She developed a genetic system in this organism and generated Mn oxidation mutants. She is genetically engineering an oxidizing factor to increase the spore's ability to bind and precipitate a variety of metals for use in metal removal or immobilization. Caspi's work addresses the mechanism of Mn oxidation by a different group of bacteria that appear to oxidize Mn metabolically during their growth. He is working on isolating genes involved in Mn oxidation to develop molecular probes for examination of natural microbial Mn(II) oxidation.

Understanding how light is produced by bioluminescent marine organisms is the focus in Dr. Frederick I. Tsuji's laboratory. He uses biochemical and molecular biological techniques in his investigations. He studies organisms such as *Apogon ellioti* (fish), *Aequorea victoria* (jellyfish), *Watasenia scintillans* (squid), *Porichthys notatus* (fish), *Symplectoteuthis oualaniensis* (squid), and *Vargula hilgendorfii* (crustacean). The cDNAs for the light-emitting proteins of *Aequorea* and *Vargula* have been cloned and expressed in *Escherichia coli* and mammalian cells. Dr. Tsuji modified aequorin, the protein of *Aequorea*, by site-directed mutagenesis and studied its luminescence properties by spectroscopic techniques.

Dr. Tebo and graduate student Lorraine G. van Waasbergen insert samples into gamma radioisotope counter.

Dr. Michael I. Latz focuses on the bioluminescence of marine organisms and the physiological mechanisms for excitation and control of light emission. He is deriving bioluminescence signatures in order to quantify both the intraspecific and interspecific differences in luminescence properties. Plankton—such as single-celled dinoflagellates—are model organisms for investigating the biophysical excitation of bioluminescence. Dr. Latz is using defined fluid flows to identify excitation thresholds and ascertain fluid properties effective in stimulation. Dr. Latz also discovered that the dinoflagellate *Ceratocorys* has a circadian rhythm of spontaneous bioluminescence that occurs in the absence of stimulation—though the mechanism through which this occurs is known.

Ecological studies of deep-sea benthic boundary layer communities receive major emphasis in Dr. Kenneth L. Smith's laboratory. Long time-series measurements (>3 years) of benthic boundary layer processes continue at a single, 4,100-m deep station in the eastern North Pacific. Results show a strong temporal relationship between the flux of particulate organic matter (food supply) and the activity of the benthic community, including the large conspicuous animals on the sediment surface. Scientists are developing a bottom transecting autonomous vehicle that will take long time-series measurements of benthic metabolism to complement ongoing long-term studies. Dr. Smith and a University of Aberdeen colleague are recording the behavior of scavenging grenadier fish using acoustic tagging tech-

niques in the deep North Pacific. Graduate student Ronald S. Kaufmann is completing a study on the energetics and sensory biology of lysianassid amphipods, a dominant group of scavengers in the deep sea.

Dr. Victor D. Vacquier's group continues study of the mechanism of sperm-egg interaction during sea urchin and abalone fertilization. The protein lysin is used by abalone sperm to make a hole in the egg envelope. They have sequenced the DNA coding for lysin to show how gene divergence occurred during the evolution of seven California abalone species. Lysin sequences are being determined for abalone species throughout the world to clarify how the sequences have changed during the evolutionary radiation of this marine mollusk genus. Dr. Vacquier's group also investigates the proteins on the sea urchin sperm that mediate the sperm's acrosome reaction.

Researchers in Dr. Benjamin E. Volcani's group study the regulation of gene expression and DNA replication by silicon in diatoms. Drs. Mark M. Hildebrand, David R. Higgins, and coworkers have generated cDNA libraries from cultures of the marine diatom *Cylindrotheca fusiformis* under conditions of silicon starvation and replenishment. Screening of isolated clones in which genes were induced by silicon and silicon repressed genes will distinguish between cell-cycle regulated genes and genes regulated by silicon.

Dr. Robert E. Shadwick studies the structure and biomechanical properties of circulatory and skeletal systems. He and graduate student Greg K. Szulgit, are investigating the mechanical properties of the sea urchin spine ligament. The ligament is a collagenous tissue with the unusual ability to undergo reversible changes in tensile properties. It is apparently under nervous control in vivo, and controlled through changes in calcium levels in vitro. Graduate student Torre Knower and Dr. Ngai C. Lai are collaborating on a biomechanical study of shark pericaridal tissue. By direct mechanical testing the pericardial septum, previously believed to be a rigid structure, has been shown to be very compliant under physiological conditions. Their results support a new model of cardiac filling in sharks, developed by Drs. Lai and Jeffrey B. Graham, and colleagues at the UCSD School of Medicine.

Other connective tissue studies under way in Dr. Shadwick's laboratory include the isolation and characterization of a biological elastomer found in the artery wall of crustaceans. They also investigate the mechanical organization of the swimming musculature and associated tendons in yellowfin tuna. The latter work is part of a joint project with Dr. Graham and colleagues to study swimming mechanics of these highly efficient pelagic fish. Graduate student Jennifer C. Nauen is characterizing the kinematics of escape swimming in the California spiny lobster and the effects of growth on morphology and swimming performance. This information will contribute to a model of swimming energetics for the life history of this commercially important species.

Dr. William A. Newman completed a work on 'Darwin and the barnacles' for a forthcoming publication on the history of carcinology (crustacean). Graduate student Tracy W. Baynes is analyzing extensive data from experiments on the effect of sedimentation and insolation on benthic communities of Pulmo Reef, Baja California Sur. Graduate student Robert J. van Syoc has sequenced mtDNA from New Zealand, Japanese, and Portuguese pedunculate barnacles. He will use his data for out-group analyses and studies involving the population structure and evolution of the local form, *Pollicipes polymerus*, and its southern counterpart, *P. elegans*.

Dr. Robert R. Hessler's group studies the functional morphology, evolution, systematics, and ecology of crustaceans. In collaboration with a University of Lund colleague, Dr. Hessler continues his system-by-system description of the internal anatomy of the most primitive living crustacean, the Cephalocarida. He also described how deep-sea isopods reacquired the ability to swim. Dr. Michel Boudrias investigated the morphology, kinematics, and fluid dynamics of swimming in the now-famous deep-sea amphipod *Eurythenes gryllus*. Graduate student Scott C. France studies dispersal in the deep sea, using scavenging amphipods from hydrothermal vents, trenches, and coastal basins as examples.

In collaboration with Dr. William F. Perrin, Southwest Fisheries Science Center, graduate student Patricia E. Rosel completed a study of the relationships among the family Phocoenidae (true porpoises). By gene amplification and direct sequencing she obtained nucleotide sequences from two mitochondrial genes from all of the species in the family. Her results prompted changes in the taxonomy of the family and reveal low levels of diversity in some populations.

Dr. Andrew A. Benson is focusing on two research projects. Endocrine changes during spawning of pink salmon, *Oncorhynchus gorbuscha*, suggest that two genes control production of the calcium-regulating hormone, calcitonin. After spawning, salmon produce a novel hormone sequence resembling that of mammals. Regulation of the path of carbon in photosynthesis in leaves and algae is being re-investigated by Dr. Benson in the light of new possibilities for control of photorespiration, a major factor reducing photosynthetic productivity. Production of glycolic acid is an indicator of oxidative degradation of the CO_2 acceptor of photosynthesis.

Dr. Lanna L. Cheng is working on the ecology of the marine insect *Halobates* by examining seasonal ocean surface samples from the Banda Sea (Indonesia).

Marine Life Research Group

THE Marine Life Research Group (MLRG) is dedicated to the study of the biology, physics, and chemistry of the California Current and its 'tributary' waters. For 43 years MLRG scientists have carried out multiagency, multidisciplinary studies of the California Current in support of State of California fishery science (California Cooperative Oceanic Fisheries Investigations [CalCOFI]). As a result of working with NOAA's Southwest Fisheries Science Center and the California Department of Fish and Game, MLRG has established the largest interdecadal time series of multivariate oceanographic data in the world. These data have become extremely valuable because baseline data for understanding regional and global change are in great demand.

Dr. Dean H. Roemmich, using these time-series data, explored the relationship between ocean warming and sea level rise along the California coastline. He found that, from 1950 to mid-1991, there has been a 3-cm steric height increase in the water column of the California Current region off Southern California. This increase coincides with a 0.8°C increase in the average temperature of the upper 100 m, 0.2°C increase at 200 m, and 0.1°C or less at 300 m. In the time series of sea-surface temperature measurements at Scripps Pier begun in 1916, the decade of the 1980s is the warmest. Such knowledge of the vertical distribution of heat in the ocean is critical to understanding its implications for climate change.

Time-series data are also essential for evaluating interdecadal and episodic perturbations, such as El Niño events. The observation of El Niño conditions in the equatorial Pacific during 1992 confirmed earlier predictions that such an event would take place. Data collected by the CalCOFI program allow researchers in the Marine Life Research Group to investigate at least some of the effects of this El Niño episode upon the California Current. As each additional event is sampled, it becomes clearer that there

Dr. Mia J. Tegner tests the clarity of water near the Point Loma sewage outfall using a secchi disk (page 46). Right, Peter Edwards and Dr. Tegner suit up to go diving.

may be large differences in effects of each El Niño upon this system.

The 1992 episode became apparent in the California Current in December 1991, when sea-surface temperatures at the Scripps Pier indicated warmer than normal conditions. The February 1992 CalCOFI cruise confirmed this. Warm conditions were observed throughout the California Current, with the largest anomalies being subsurface, occurring in the upper thermocline. The northward-flowing counter current in February was more than twice as wide as normal, and chlorophyll levels throughout the California Current were low. The intensified counter current and low chlorophyll were also seen in observations made in the coastal region of Northern California during March. However, by late April the oceanic patterns had changed dramatically. The northward countercurrent had disappeared, and it was replaced by the strong southward flow characteristic of the California Current. This abrupt return to a more typical physical structure coincided with a strong increase in chlorophyll and primary production.

Nearshore evidence of a perturbation continued on into mid-1992. The second highest sea height in the 68-year record occurred in January 1992. The February, March, April, and May sea heights set new records for each of those months. The Scripps Pier monthly mean sea-surface temperatures for April and May also set new 76-year highs of 19°C (3.46°C above the mean) and 19.3°C (3.3°C above the mean) respectively. By June, both the sea height and the sea-surface temperature had returned to near-normal amplitudes. A preliminary analysis of the data collected on the July CalCOFI cruise appears to confirm the return to more normal conditions in the California Current. The rapid evolution of structure observed during 1992 illustrates the need for frequent data collection during such events.

Dr. Thomas L. Hayward's studies off the Northern California Coast in March 1992, coincided with a period of El Niño conditions. He collected additional data for his studies of the physical processes that regulate the abundance and growth rate (primary production) of phytoplankton in the ocean. Prior observations showed that there are high levels of chlorophyll in the spring and a clear connection between circulation patterns and the distribution of phytoplankton. However, circulation in the March 1992 study region differed from the typical structure because of the El Niño conditions. A pattern of broad northward flow replaced the more typical pattern of strong equatorward flow, and was concentrated in a coastal jet and perturbed by eddies and fronts. Chlorophyll

Dr. Tegner and Edwards lower a tray loaded with instruments and sampling devices to study the effects of the sewage spill during the period when the water was quarantined to divers with standard gear.

and primary production were also lower than expected in March. Scientists are using the contrast in structure between this and prior years to investigate how the circulation affects the plankton distribution.

Marine sediments are another type of time series, they are laid down in annual varves or bands. MLRG researchers Dr. Timothy R. Baumgartner and Andrew Soutar, and a colleague from Mexico continue to reconstruct the last two millennia of the history of the Pacific sardine (*Sardinops sagax*) and northern anchovy (*Engraulis mordax*) populations based on sediments taken from the anaerobic bottom of the Santa Barbara Basin. They have recalibrated the scale counts by comparing the historic biomass of these species to the deposition of scales in historic times, then they hindcast the population for the last 200 years. Interdecadal correlation between anchovy and sardine population sizes is near-to-nil, while there is a moderate positive correlation between the two species on time scales of centuries. Their data show nine major collapses of the sardine population over a period of 1,700 years, with an average recovery time of 30 years. The present recovery of the Pacific sardine population, following the notorious collapse of the population in the 1940s, is typical, both in rate and magnitude. These findings may be significant to the future management of the sardine fishery.

Drs. Mia J. Tegner and Paul K. Dayton refocused their kelp forest research during 1992 to evaluate the impacts of a break in the Point Loma sewer outfall. Normally, 680,000,000 liters (180,000,000 gallons) of advanced-primary-treated sewage per day is released through diffusers 3 km offshore. During the 1992 spill this amount was released through a point within kelp forest depths. The spill reduced light penetration, which in turn caused significant inhibition of giant kelp recruitment (in experimental outplants of microscopic stages). This effect disappeared 11 days after the repair was completed. The break occurred during an El Niño event, manifested in warm waters with reduced nutrient concentrations so it is unlikely that the kelp would have germinated in the absence of a spill. High ammonium concentrations in the sewage may have damaged the kelp canopy close to the spill. However, the ammonium strikingly benefitted the nutrient-depleted surface canopy beyond 1 km from the break, when compared to the La Jolla kelp forest,

which is out of range of the spill. No significant effects were observed in Point Loma kelp forest animals. Shortly after the repair, strong upwelling (of cold, nutrient-rich water) improved the conditions for kelp recruitment and growth, suggesting that the Point Loma kelp forest will quickly recover from normal winter losses, El Niño conditions, and the sewage spill. The lack of important environmental effects observed during a highly concentrated spill was used by the city of San Diego to support its position that secondary treatment is not required to protect the nearshore environment.

Dr. Michael M. Mullin continues his measurements of per capita reproductive rates of *Calanus pacificus*, an important member of the California Current zooplanktonic fauna, and he added similar measurements for another copepod, *Rhincalanus nasatus*. The decreased concentrations of chlorophyll (a proxy for plant biomass) associated with anomalously warm water observed during February 1992 (a manifestation of a northern El Niño event), resulted in limited reproduction. By April both temperature and chlorophyll indicated a return to more normal conditions, and the geographical pattern of reproductive rate had become similar to that observed in non-El Niño years.

Dr. Angelo Carlucci's group continued work on the microbiology of sea-surface microlayers. They found that microbial biomass, dissolved free amino acids, and dissolved combined amino acids (DCAA), were always enriched in surface microlayers when compared to water from 10 cm below the surface (in waters collected off the coast of San Diego and the Channel Islands near Santa Barbara). At 9 of 13 sites sampled, the metabolism of glutamic acid by microbial populations was higher in surface microlayers than at 10 cm depth. At those sites where higher metabolism was observed in 10 cm waters, elevated winds were responsible for mixing of the water, and there was an input of dissolved constituents to deeper water from microlayers. Turnover times for amino acids were longer for microlayers, in part, because of the higher levels found in these environments.

Dr. Tegner dives into water to make observations after the outfall was repaired.

MLRG investigators have carried out two studies on the biology of seamounts. Dr. Loren R. Haury and colleagues found that dramatic gaps are formed in the abundance of zooplankton over seamounts each evening when migrating zooplankton move toward the surface from depths below the summit. The most graphic evidence of this phenomenon was found using acoustic imaging at Sixtymile Bank, a submarine ridge 60 nautical miles (111 km) southwest of San Diego. The gaps, seen both in acoustic records and in net tows, are caused by the physical displacement of the zooplankton as currents sweep them around the shallow topography during the daytime and by the intensified predation on them by animals that live on and above the bank.

Dr. Lisa Levin's seamount biology work involves the physical, chemical, and biological processes that structure populations and communities of sediment-dwelling invertebrates. Her studies on the infauna of Fieberling Guyot reveal the dramatic influence of intensified currents and sediment transport on species composition, abundances, and behaviors. Invertebrate larvae, 'tagged' with rare-earth elements, were released and recaptured. Her study showed that it may be possible to use isotope markers in future investigations of seamount fauna population dynamics.

Marine Physical Laboratory

R. Pinkel

SCIENTISTS AT the Marine Physical Laboratory (MPL) study ocean acoustics, physical oceanography, marine chemistry, and marine geophysics. They also develop instrumentation, platforms, and signal processing techniques to observe the seafloor and the water column.

The Upper Ocean Physics Group's primary focus was participation in the Arctic Leads Experiment (LEADEX). Leads—open cracks in the otherwise complete ice cover of the Arctic Ocean—are becoming a subject of great environmental interest because of concern over global warming. Attention is being focused on the polar ice caps and their role in reflecting incoming solar radiation. The ice caps are a significant contributor to the overall albedo of the earth. The concern is that as the climate warms, the ice caps will shrink. The amount of incoming radiation, which they reflect could diminish, thus encouraging still further warming.

Winters in the high Arctic are dry and clear. Moisture is frozen-out of the lower atmosphere, leaving a desert-like climate for the surface of the polar seas. However, as cracks appear in the ice cover, the cold, initially dry air is exposed to seawater 40°C (70°F) warmer. Conditions would be similar in San Diego during a Santa Ana—with the humidity low and air temperature 27°C (80°F), provided the ocean were a balmy 65°C (150°F)! The local evaporation rates over an open lead are intense, perhaps caused by incoming solar radiation. Sheets of 'steam' are often seen rising from the surface of a fresh lead.

As spring approaches, leads increase and the clear Arctic sky is obscured by a layer of low-lying fog. The Arctic ice cap is an efficient reflector of incoming solar radiation from the time the sun first appears at the end of the Arctic winter, until the summer cloud cover effectively blankets the earth's surface.

Scientists with LEADEX study the details of this process and the corresponding

phenomena that occur on the ocean side of the interface. A base camp was established on the ice in the Beaufort Sea, approximately 240 km north of Prudhoe Bay, Alaska. Teams of scientists lived and worked in small, lightweight huts. When leads appeared within range of the base camp (32 km), helicopters could quickly deploy the scientific teams.

Measurement of oceanographic variables is difficult in the lead environment. The cracks, from 1 to 1,000 m wide, constantly change under the influence of wind and current, until the new ice surface has the structural strength to resist. When a young lead starts to close, it can trap the instruments suspended within. If an old lead starts to reopen, the new open water is often far removed from the 'safe' ice at the previous edges, separated by hundreds of meters of thin ice formed in prior opening episodes.

MPL Doppler sonar instruments, developed for the remote sensing of flows in the ocean interior, transmit narrow beams of high frequency sound. The sound scatters from plankton drifting in the water. From the Doppler shift of the returning echo, the velocity of the water can be inferred as a function of range along each beam. Doppler sonar is an ideal tool for exploring the oceanographic environment of a lead. A sonar can be mounted at the edge of a lead and directed inward toward the center. Convective cells and other lead oriented flows can be directly resolved by the sonar. The interaction of these phenomena with the larger scale oceanographic circulation can then be studied.

A new generation of sonar technology was implemented by Dr. Robert Pinkel's Upper Ocean Physics Group for LEADEX. Rather than using one, two, or four discreet sonar beams, a phased-array was developed that resolved 56 discrete beams in a 45° planar sector. The instrument, the size of a large briefcase, operated at 195 kHz acoustic frequency and transmitted to a maximum range of 300 m, with 3-6 m range resolution.

Group researchers designed the acoustic array and sonar housing, and coordinated logistics for the experiment. They designed the analog transmit-and-receive electronics, using miniaturized surface-mount technology, and developed the optical data transmission link that coupled the sonar to the leadside processing unit. A computer with a digital signal processing card was used to record and process the one-third megabyte per second data rate in real time. Dr. Mark A. Merrifield and colleagues developed the software for the system.

The project developed from conception to a finished instrument in less than nine months. The instrument was flown north to the

R. Pinkel

Helicopter carrying an experiment hut arrives at a lead in the Beaufort Sea.

Dr. Robert Pinkel's group deploys a Doppler sonar in an Arctic lead (page 50).

Christopher P. Neely checks Doppler sonar instrumentation, which was deployed on the edge of a lead to measure the flows in the ocean interior. Laboratory/living huts are in the background.

R. Pinkel

LEADEX base camp shortly before the first active lead was sighted. Group researchers deployed the instrument with few of the difficulties associated with bringing new technology to life in a harsh environment. Learning how to exploit the instrument's capability in the very short time available at the lead edge was the greatest challenge.

Strong wind events (storms) generate the leads and LEADEX, in the end, was hampered by good weather. Storms were few and far between this spring in the Beaufort Sea. Only two leads were extensively studied by the LEADEX team. Nevertheless, the information return was extensive, particularly concerning the interaction of lead convective activity with the ambient mixed layer and internal flows.

As the LEADEX sonar data are being analyzed, preparations are under way to take the instrument to another center of intensive ocean atmospheric interaction, the tropical Pacific. The western tropical Pacific will be extensively studied in the TOGA-COARE program. Scientists in this program will examine air-sea interaction processes in great detail, with the hope of further understanding the link between the tropics and higher latitude climate. This was a year of fire and ice, at the least, for the Upper Ocean Physics Group.

Deep Tow Activities

Scientists in the Deep Tow group, under the direction of Dr. Fred N. Spiess, developed a system for logging and placing instruments in deep-sea boreholes from ocean research ships. This project had a short test at sea using R/V *New Horizon*.

The primary innovation in the development and use of the MPL Deep Tow system is the addition of a swath mapping echo sounder. This will gather topographic data in a manner and format similar to that for hull mounted systems (Sea Beam), but with a 100 to 1,000 times greater resolution factor by virtue of operating close to the seafloor. Such data can be used to test hypotheses about scale dependence of ocean bottom roughness. The new system will operate 50 to 500 m off the seafloor and will have 61 overlapping 2° beams covering a 60° arc below the vehicle.

The primary Deep Tow operation for the year was an investigation

of the nature of the Kane Fracture Zone near its junction with the Mid-Atlantic Ridge at 23.5°N, 45°W. Dr. Spiess was among the co-chief scientists on this expedition aboard R/V *Knorr* (Woods Hole Oceanographic Institution). While the usual Deep Tow subsystems were used, principal emphasis was on use of the 100 kHz side-looking sonar (SLS) in a mode adapted to acoustic imaging of large escarpments. With this arrangement acoustic pictures of the steep south wall of the Kane Fracture Zone were produced, revealing massive gabbro exposures (confirmed as vertically banded by Deep Tow photographs), one stretch being 500 m wide and 1,500 m long. This work sets the stage for a subsequent cooperative venture using the French submersible, *Nautile*, for detailed observation and sampling.

Surface Waves and Currents

Dr. Jerome A. Smith continues his investigations of the interactions of surface waves and currents in the open ocean. The combined effects of wind-drift and waves can cause the formation of Langmuir circulation in the top layer of the ocean. Langmuir circulation can be important for mixing wind-generated momentum throughout the mixed layer; however, it has proven difficult to observe in the open ocean. Recent observations reveal Langmuir circulation at scales from three times the mixed layer depth (3 x 60 m) down to the resolution of the sonar systems (2 x 3 m). One data set is particularly exciting. It shows an initial growth phase in the development of Langmuir circulation. These systems also measure the surface wavefield. Graduate student Gregory T. Bullard is working on the estimation of wave directional spectra using two data sets.

Graduate student Karl F. Reider is developing high-resolution directional estimators from the combined data set. With corrections for the motion of FLIP, it should be possible to develop an estimator that can distinguish directional peaks only a few degrees apart.

In Situ 3-D Imaging

Dr. Jules S. Jaffe's Ultrasonic Sonar Imaging Group developed a 3-dimensional underwater imaging system, primarily for tracking zooplankton in 3-dimensions. The system is composed of two sets of 8 side-scan-like array elements operating at a frequency of 420 kHz, which are stacked and pointed in slightly different directions (2°). One of the sets of 8 transducers is used as a transmitting array and the other set is used as a receiving array.

The system transmits on a single one of the transducers and the reflected sound is simultaneously received, amplified, and digitized on the other set of 8 transducers. Then, the next transducer, which is pointed in a slightly different direction, is activated. Again, the reflected sound is received by the other set of 8 transducers and recorded. This process continues until all of the transmitting transducers have played their sounds and it is then repeated. Considering the 3-dimensional space as a matrix, the system scans the space by transmitting on the rows, one by one, and receiving on all of the columns each time. The pointing angles of the transmitting and receiving transducers provide the azimuth and bearing resolution; the time delay of the signals, after transmission, provides the range information.

Researchers in Dr. Jaffe's group also work on underwater optical imaging systems. Several design options are possible, including use of a system of computer programs that models the entire imaging process. Predicted performance of the imaging system in different underwater scenarios can be examined, and optimal designs can evolve. For this purpose, Dr. Jaffe developed a computer program called UNCLES (Underwater Camera Light Experiment System). UNCLES has been used to design a number of underwater imaging systems currently being used both on small robots (ROVs) and larger platforms.

As a simple criterion for evaluating imaging system performance, the researchers characterize the range in total attenuation lengths (inverse attenuation constants) at which collection of acceptable images is possible. They define acceptable images as having both adequate contrast transmittance $C_t(x,y)$ (to be able to resolve objects with differing reflectivity [>.5]) and adequate power to be recorded with whatever photographic or video media is used.

The simplest type of imaging system, a camera and a light source, is usually limited to a range of 1-2 attenuation lengths if the equipment is placed in close proximity. This type of imaging system is usually backscatter limited.

Larger imaging ranges can be achieved by using camera/light separation techniques (considering only conventional camera and lighting). Ranges of 3-5 attenuation lengths can be achieved with this method if enough power is available. If performance in excess of these parameters is desired, less traditional means of forming images will be needed. Two options include gating both the source and the receiver, and scanning the source with either concurrent scanning of the receiver or image sorting using digital techniques.

Sonar sensing of the underwater environment is a natural alternative to visual imaging in situations where greater range is desired. In addition, sonar images are taken in a way that makes it easy to figure the distances of the objects themselves. Underwater 'high frequency' sonar imaging has been an area of intense research interest. The basic principles upon which almost all of these sonar devices work stem from the relationship between an array and its far field.

A complication occurs in sonar imaging that is not typically present in the light optical case. Because most sonar imaging systems use

almost single wavelength sound and most surfaces are rough with respect to this wavelength (1.5 mm @ 1 MHz), the reflection of sound is considered equivalent to the superposition of a random distribution of time-delayed wave forms. This leads to a special kind of multiplicative noise called speckle. For fully developed speckle, the signal-to-noise level is one. Thus, these images are very noisy.

Acoustic Arrays

Drs. William S. Hodgkiss and John A. Hildebrand are developing several acoustic arrays and autonomous recording capsules for deployment during the Bottom Reverberation Experiment in July 1993. This experiment will involve the participation of researchers from several universities and government laboratories. They hope to clarify the fundamental physics governing the interaction between low-frequency, low-grazing angle acoustic energy and the seafloor. The data gathered will enable researchers to study the physics of the scattering process and to quantify scattering characteristics as a function of physically meaningful parameters such as insonified area, grazing angle, bottom material properties, and bottom roughness.

Although seafloor scattered wavefields have been studied previously, many of the seafloor characteristics important to their understanding have not been measured concurrently. Scattering may vary spatially in the ocean because of variations in seafloor roughness, sediment cover, bottom elastic properties, and water depth. For this experiment special emphasis is on obtaining a detailed description of the bottom of the western side of the Mid-Atlantic Ridge.

Each of four reverberation arrays will have 64 hydrophone elements with 1.875 m interelement spacing ($\lambda/2$ at 400 Hz). The time series from the array elements will be sampled at f_s = 1.5 kHz using 24 bit A/D converters and multiplexed onto a single digital data stream for transmission to the recording capsule. Also, 16 12-kHz navigation receivers will be embedded in each array for localizing the array elements during the experiment.

Each of the four autonomous recording capsules will use a 60 cm diameter aluminum pressure vessel as the primary electronics housing. The array digital data stream will be recorded on an exabyte-8500 8-mm cassette recorder (5 gigabytes/tape).

Dynamics, Acoustics, and Remote Sensing of Breaking Waves

Dr. W. Kendall Melville is studying the dynamics, acoustics, and remote sensing of breaking waves. Breaking waves play a role in processes that occur at the ocean surface. Wave breaking limits the height of surface waves, dissipates energy, transfers momentum from waves to currents, provides a source of turbulence for mixing the surface layers of the ocean, enhances gas transfer across the air-sea interface, and batters oceanographic instruments, ships, and other man-made structures.

However, it is hard to define the precise role breaking waves play in these processes. In the field, breaking is intermittent and the direct detailed measurement of the physical variables that quantify breaking is beyond the scope of available oceanographic instruments. Numerical simulation of waves up to breaking has advanced, but not proceeded beyond the onset of breaking to the more interesting turbulent flow that evolves. These difficulties have led to the use of laboratory investigations of breaking and, most recently, to the use of both acoustic and microwave techniques to study breaking waves in the field.

Dr. Melville's early laboratory experiments found one of the causes of breaking to be certain classes of hydrodynamic instabilities. He later found that all the basic dynamical variables describing two-dimensional breaking evolve simply in time and correlate with the prebreaking wave variables.

Dr. Melville is seeking methods of measuring breaking to use in the field. Breaking waves are one of the major sources of sound at the ocean surface, and they may also be the source of 'sea spikes' in microwave scattering at the sea surface. Dr. Melville hopes to quantify these effects in the laboratory and use them as remote sensing tools to study breaking in the field. Working with graduate students at Massachusetts Institute of Technology and Dr. Michael J. Buckingham, he found that the mechanical wave energy dissipated by breaking waves correlated with both the sound radiated by breaking and with the microwave scattering. These experiments showed that acoustic and microwave techniques could possibly be used to study the dynamics of breaking in the field.

Dr. Melville and colleagues are investigating the mechanisms underlying the generation of sound by breaking waves. Clearly, the sound radiated is associated with the air entrained by breaking and its subsequent break-up into bubbles. For gently breaking waves, they found that a simple dipole model of the sound radiated by single resonant bubbles agreed with laboratory measurements at acoustic frequencies greater than 500 Hz. For actively breaking waves, accompanied by the entrainment of large volumes of air, the identification of the acoustic properties of individual bubbles is more difficult, and the bubble cloud may be treated as a continuum. Using the electrical properties of the bubbly mixture to measure the volume fraction of air, their experiments showed that the work done against buoyancy forces in entraining the air could account for up to 50% of the mechanical energy lost from the wave field at breaking. Thus, this process accounted for the previously measured correlation between the dynamics and acoustics of breaking.

Marine Research Division

THE RESEARCH activities in the Marine Research Division span the disciplines of biological oceanography, marine chemistry, physical oceanography, and marine engineering. This annual report includes descriptions of a portion of these activities.

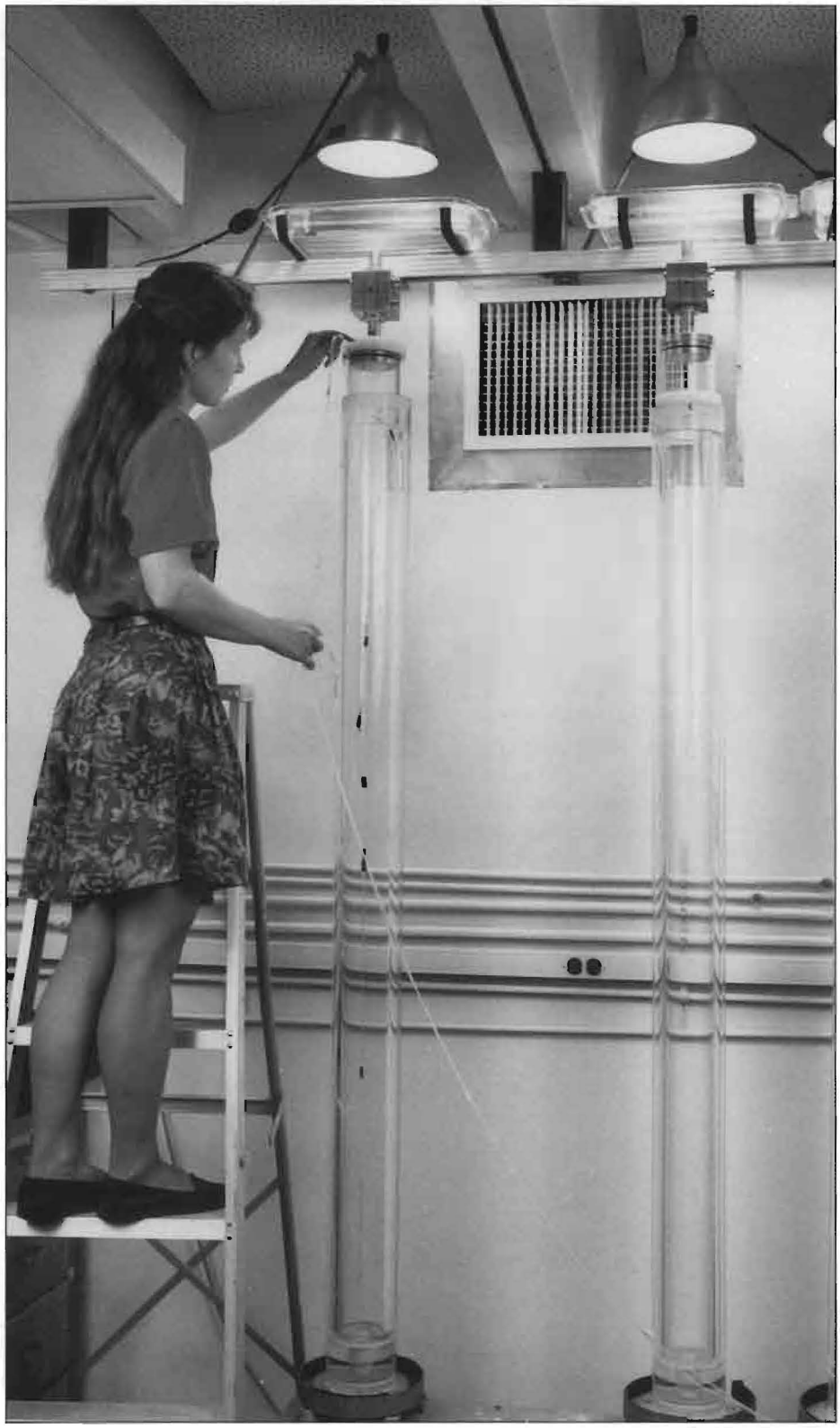
Drs. Mizuki Tsuchiya, Lynne D. Talley, and a colleague, are studying the large-scale circulation of the South Atlantic Ocean using hydrographic data they collected along a long meridional section extending from South Georgia Island (54°S) northward to 0°40′N. Their data reveal a complex structure within the North Atlantic Deep Water, which penetrates into the South Atlantic and occupies a thick layer extending roughly from 1,500 m to 4,000 m. This layer is closely related to the basin-scale circulation pattern of the deep water. The scientists also found evidence that the westward flow of Antarctic Intermediate Water (~800 m) within 2° of the equator is flanked by eastward flows on both sides. A strong westward flow of deep water from the Weddell Sea immediately south of the Falkland Ridge, and a high degree of vertical and meridional homogeneity of near-bottom water in the Brazil Basin were also detected.

Dr. Peter M. Williams and colleagues extended their investigations of organic carbon cycling in the oligotrophic gyres of the North Atlantic and Pacific oceans to include the more productive waters 120 km off Pt. Conception, California. They collected dissolved, suspended, and sinking particulates, and sedimentary organic matter to measure isotopic signatures (14C, 13C) in both the bulk material and individual organic components. Initial measurements of ^{14}C ages do not indicate an appreciable contribution of modern carbon to the deep-water dissolved organic carbon pool at this eutrophic site.

Scientists in Dr. Gustaf Arrhenius's group study the characteristics of the earth's earliest ocean and atmosphere. They focus on the processes that could, in this environment, have led to the origin of life. In both

Dr. Maria Vernet at work (page 55).

Graduate student Cynthia T. Tynan prepares to sample dinoflagellates in Couette cyclinders while studying the effects of small-scale turbulence on vertical migration.



modern and ancient organisms, the genetic materials RNA and DNA are based on a backbone chain structure of sugar phosphate. The sugars are exclusively the five-carbon ribose and deoxyribose. A classical question in the origin of life is how selective sugar formation could take place in the absence of enzymatic mechanisms. A related problem is how simple source molecules for these abiotic systems could be brought together from the low concentration expected in the primordial ocean, (where the concept of a concentrated 'probiotic soup' has proven difficult to sustain on geochemical grounds).

The discovery that minerals are effective mediators of selective sugar formation is a clue to these problems. The minerals in question are double-layer hydroxides (common in the modern ocean as weathering products on marine basalts). In the oxygen-free Archean ocean they were abundantly represented by ferroferric hydroxide—believed to be the precursor of the huge iron ore formations that are the major source for modern steel technology. These minerals have a remarkable capacity for sorption of anions such as phosphate, from a highly dilute state, creating a two-dimensional, concentrated, internal solution.

In collaboration with a research group in Switzerland, Dr. Arrhenius demonstrated that these minerals in contact with dilute solutions of simple aldehyde phosphates (glycolaldehyde phosphate) in concentrations as low as 10^{-5}M, catalytically couple these molecules to larger units in a highly selective fashion. Thus, they arrive in the additional presence of formaldehyde at the pentose sugar ribose, and alone at the hexose sugar altrose, as the main products, both as phosphate esters. The high yield and simplicity

Dr. Vernet inserts sample bottles on a plankton wheel to study small-scale turbulence for a red-tide dinoflagellate growth study (above left). Cultures of dinoflagellates are maintained for experimental use (above).

of the latter reaction has led to the proposition that early life was based on hexose sugar instead of pentose.

Their work contributes only a piece to the complex puzzle of the creation of nucleic acids and peptides without the aid of enzymes. Many questions remain to be solved. How initial phosphate esterification of simple aldehydes could take place in aqueous solution, and how cyanide-derived nitrogen bases or other recognition molecules could be selectively synthesized and attached to the sugar phosphate chains are two important issues. Again, the hydroxide minerals prove highly efficient in concentrating cyanide species. This capability is used in efforts to exploit the reactions between simple organic molecules in the interlayer of catalytically active minerals for the purpose of modeling the origins of life.

The University of California Marine Bio-Optics Group (UCMBO), an MRD intercampus group, is directed by Dr. Raymond C. Smith at UC Santa Barbara, with Scripps facilities coordinated by Karen S. Baker. The group studies theoretical and applied problems in marine optics by using both experimental work at sea and modeling. UCMBO scientists employ profiling instruments, moored instruments, and satellite imagery to assess the links between ocean optics and wavelength dependent processes includ-

ing the productivity of marine phytoplankton. They also investigate the ultraviolet radiation reaching the earth's surface and its impact on aquatic environments. As members of the first five-year team of the NSF Long-Term Ecological Program (begun in 1991 at Palmer Station, Antarctica), their work includes yearly five-month Palmer-based nearshore monitoring and work at sea. The Antarctic LTER program focuses on the ecological processes that link the extent of annual pack ice to the biological dynamics of different trophic levels. UCMBO scientists are also members of the Sequoia 2000 consortium (including University of California research groups and Digital Research Corporation) who are developing strategies to deal with the Earth Observing System.

Research in the laboratories of Dr. D. John Faulkner is directed toward the isolation and identification of new pharmaceuticals from marine invertebrates and the role of bioactive chemicals in the marine environment. In collaboration with scientist from Bristol-Myers Squibb Company, the chemists in the group discovered a new inhibitor of epidermal growth factor that may have potential as a treatment for certain forms of cancer. In collaboration with pharmacologists at UC Santa Barbara, Scripps researchers have identified a new class of phospholipase A_2 (PLA_2) inhibitors that are now being synthesized. The chemical mechanisms by which manoalide, luffariellolide, and scalaradial inhibit PLA_2 have been revealed by a series of spectroscopic and biochemical studies.

One of the most intriguing questions in marine natural product chemistry concerns the role of symbionts in the synthesis of metabolites extracted from marine invertebrates. A study of the sponge *Dysidea herbacea*, which contains large quantities (up to 50%) of the symbiotic blue-green alga *Oscillatoria spongeliae*, has revealed that a representative of an unusual class of polychlorinated compounds is localized in the algal cells. Therefore it is assumed to be synthesized by the alga. Similar experiments to localize other marine natural products are in progress.

In Dr. Joris Gieskes's laboratory, researchers study the geochemistry of borehole fluids obtained from re-entry of abandoned oceanic boreholes drilled during the Deep Sea Drilling Project (DSDP) and the Ocean Drilling Program (ODP). Samples collected recently using a submersible directed re-entry system and the ODP are of particular interest in identifying an aquifer in DSDP Hole 534 off the coast of Florida. They also delineated progressive geochemical trends in Hole 504B and compared them to previous re-entry results from legs characterized with lesser bottom borehole temperatures (lesser basement penetration). Previous work suggests that reactions between borehole fluids and basaltic rubble at the bottom of the hole were most likely the cause of the observed changes in composition of the borehole fluids.

In Dr. Gieskes's laboratory graduate student Chen-Feng You is studying the geochemistry of boron and beryllium using samples from ODP leg 131 in Nankai Trough. These elements are of particular interest in studies of hydro-geochemical processes affecting sediments in subduction zones. Mobilization of these elements during subduction has been postulated on the basis of anomalously high concentrations of both B and Be (especially radioactive ^{10}Be) in subduction zone related arc magmas. The processes that cause the mobilization of these elements are of particular interest.

Drs. William H. Thomas, Carl H. Gibson, and Maria Vernet continue their work on the inhibition of red-tide dinoflagellate growth by laboratory-induced, quantified turbulent mixing. These microalgae are inhibited by very low levels of turbulence, equivalent to that generated by 4-7 knot winds at the sea surface. Their results may partially explain why red tides are associated with very calm seas.

The activities of the Ocean Engineering Research Group, under the direction of Dr. Richard J. Seymour, include a variety of investigations. The Coastal Data Information Program, directed by David Castel and Dr. Seymour, continues studies based on OERG wave network data. Investigations included sediment transport at Santa Cruz Harbor and the performance of a new breakwater at Fisherman's Wharf in San Francisco Bay. Development work continues on a rugged and flexible microprocessor based field data logging system. Their effort included testing the system under realistic field conditions and making improvements to the controlling software. A study is under way on instrumenting an oil drilling platform in 180-m water west of Point Conception, California to elucidate deep-water directional wave spectra.

Several projects in the Ocean Engineering Research Group are being conducted by graduate students. These include numerical modeling of the excitation of seiches within harbors, investigations of bedload sediment transport under waves, and study of beach profile response to waves. Other graduate student studies involve analysis of wave directionality and the corrosion fatigue of graphite composite tethers.

The Polar Research Program, headed by Dr. Osmond Holm-Hansen, participated in three major field programs this year. The multidisciplinary RACER (Research on Antarctic Coastal Ecosystem Rates) program used R/V *Polar Duke* in the Gerlache Strait and in the Bellingshausen Sea to study factors involved in the demise of the annual spring phytoplankton bloom. Complete depletion of inorganic nitrogen and phosphorus was documented at some stations. This depletion resulted in a subsurface chlorophyll maximum, commonly found in oligotrophic waters. Scripps graduate

students E. Walter Helbling and Virginia E. Villafane, with researchers from Argentina and Chile, participated in the NOAA-directed United States Antarctic Marine Living Resources Program. This program focuses on the dynamics of predator-prey relationships in the area around Elephant Island.

A third field program involved the effect of solar ultraviolet radiation (UVR) on phytoplankton, in particular, the enhanced UV-B radiation resulting from ozone depletion in the stratosphere. These studies were done in both polar and tropical waters. Although Antarctic phytoplankton synthesize UV-screening pigments, solar UVR causes a loss of integrated primary production (approximately 10%) during the summer months. Phytoplankton in tropical waters, which are exposed to much higher fluences of UVR than phytoplankton in polar regions, do not show any significant decrease in photosynthetic rates when exposed to direct solar radiation. This finding is of interest to those concerned about possible increases in UVR in the Northern Hemisphere.

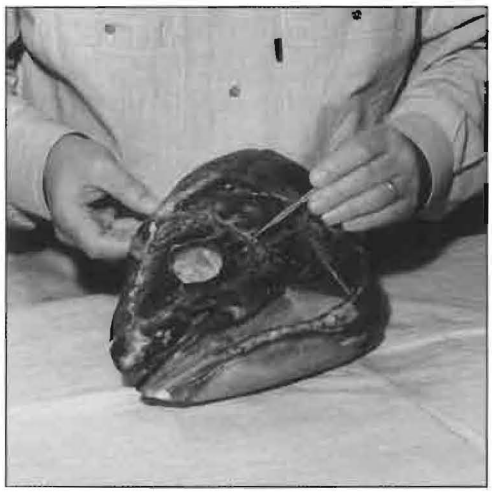
Research in Dr. Fenical's group centers on the organic chemistry of marine plants, animals, and microorganisms. Programs to evaluate the functional roles of these compounds and to explore their utilization in medical research and chemotherapy are under way.

A collaborative program with Drs. H. Kang and N.-Y. Lee, and researchers from the University of North Carolina investigates the chemical defensive adaptations of Caribbean-based plants and animals. Working from the University of Miami's R/V *Columbus Iselin*, Scripps researchers provided solid evidence of the evolution of sophisticated defensive adaptations that involve bioactive chemicals. This study aims to explore the complex chemical interactions that appear to form the basis for survival in predator-rich tropical marine environments.

The Sea Grant trainees in Dr. Fenical's group continued a study of natural products chemistry of marine ascidians and marine bacteria as part of a program to discover new anti-inflammatory agents from marine sources. In a collaborative program with UC Santa Barbara, researchers found several new classes of active agents. This year, a new compound with activity equal to or greater than existing drugs was discovered to be produced by a marine bacterium. Studies to develop this compound as part of an industrial alliance are being initiated.

National Institutes of Health-supported research in Dr. Fenical's group is focused on developing marine compounds for the treatment of cancer. In collaboration with Bristol-Myers Squibb, over 600 marine organisms have been evaluated over the past year. Invertebrate samples were collected in both the Caribbean Sea and Pacific Ocean. One new area under development is the assessment of the biomedical potential of marine microorganisms, particularly bacteria. Compared to the antibiotic-producing bacteria from the soil, which have yielded over 115 clinically used antibiotics and antitumor agents, analogous marine microorganisms have been almost completely overlooked. Scientists in this program develop new methods for the isolation and cultivation of bacteria from unique saline environments. To date, over 4,000 bacteria and fungi have been isolated and cultured. Methods to cultivate marine microorganisms in large-scale have been developed. This program, still in development stages, has yielded significant information that indicates marine microorganisms are an untapped biomedical resource.

Neurobiology Unit

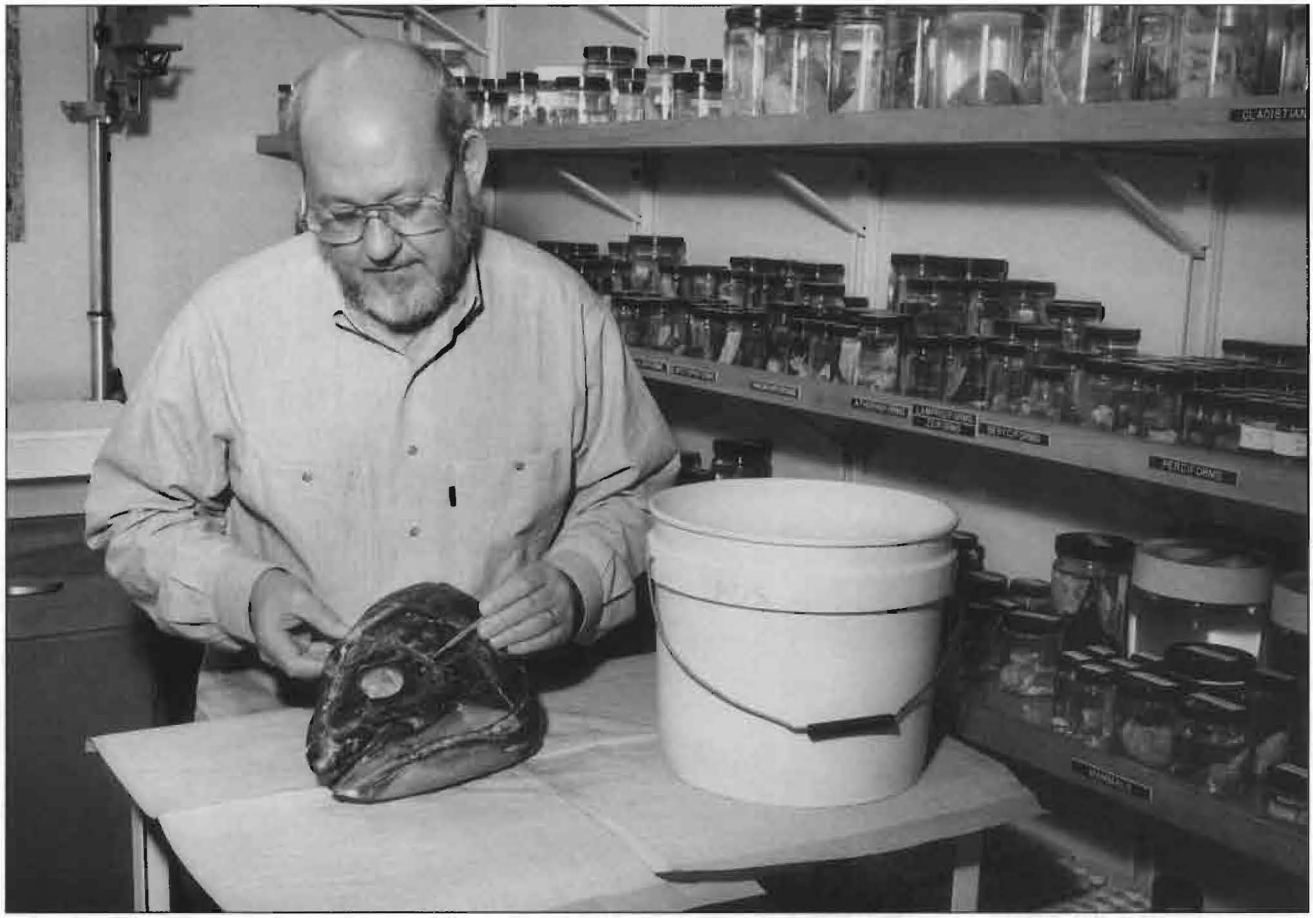


THE Neurobiology Unit, a collaboration with Scripps and the UCSD School of Medicine, is part of the Marine Biomedical Program. The researchers in the Neurobiology Unit have long held a great interest in the lateral line system in fishes.

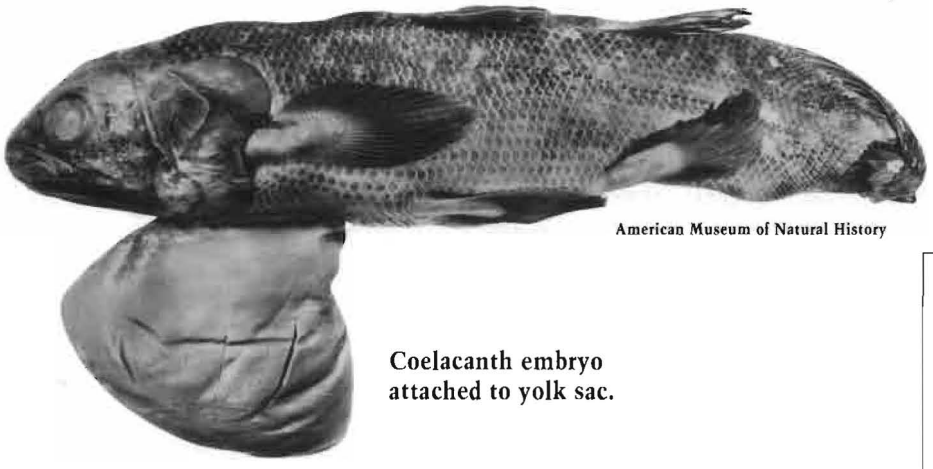
Their focus intensified with a three-year collaborative study on the cranial nerves innervating the lateral line system of the coelacanth *Latimeria chalumnae*. Dr. R. Glenn Northcutt, a University of Massachusetts colleague, and the American Museum of Natural History are undertaking the effort.

The coelacanths had been thought to be extinct for as long as the dinosaurs. When they were discovered shortly before World War II, these deep-dwelling fish caused as much excitement as a living dinosaur might cause. Fewer than 200 coelacanths have been captured since then, almost all in the Comoro Islands. A living coelacanth is exciting because it is the closest surviving relative of the fishes that gave rise to land vertebrates. It gives scientists the opportunity to examine an animal that has changed little in 60 million years, unlike its land-migrating cousins, who evolved into amphibians and subsequently, reptiles, birds, and mammals.

Adult coelacanths are large (about 1.5 m long), and most specimens have been poorly preserved. Information about their sensory systems has remained incomplete. Dr. Northcutt and colleagues were able to examine the cranial nerves and lateral line system because of a colleague's participation in an Explorer's Club expedition to the Comoro Islands. Also, a well-preserved fetal coelacanth and new adult material recently became available at the American Museum of Natural History. This collaborative study yielded three conclusions. First, *Latimeria chalumnae* retains most, if not all, the lateral lines present in the earliest vertebrates. Second, there are six pairs of cranial nerves associated with the lateral line system, and they are more distinctly developed in *Latimeria* than in any other living vertebrate. Third, these observations confirm inferences based on the embryology of extant vertebrates and extrapolations from the fossil record.

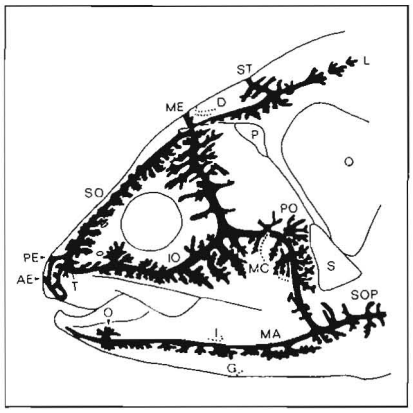


Dr. R. Glenn Northcutt examines the lateral line canals on the head of a preserved coelacanth (*Latimeria chalumnae*) (page 60 and above).



American Museum of Natural History

Coelacanth embryo attached to yolk sac.



Drawing of latex injected lateral line canals of an adult coelacanth.

California Space Institute


D. Lubin

THE California Space Institute (CalSpace), headquartered at Scripps, conducts and supports both space-related and earth-related scientific, educational, and technological research on UC campuses and at the Lawrence Livermore and Los Alamos national laboratories. CalSpace has developed strong ties with Scripps through joint faculty appointments and collaborative research in climate dynamics and global change. CalSpace director Dr. Sally K. Ride and assistant director Dr. David P. Rogers are building the institute's in-house research and extending its role in education. Research done in the Antarctic by CalSpace scientists and activities in support of education and space research are featured here.

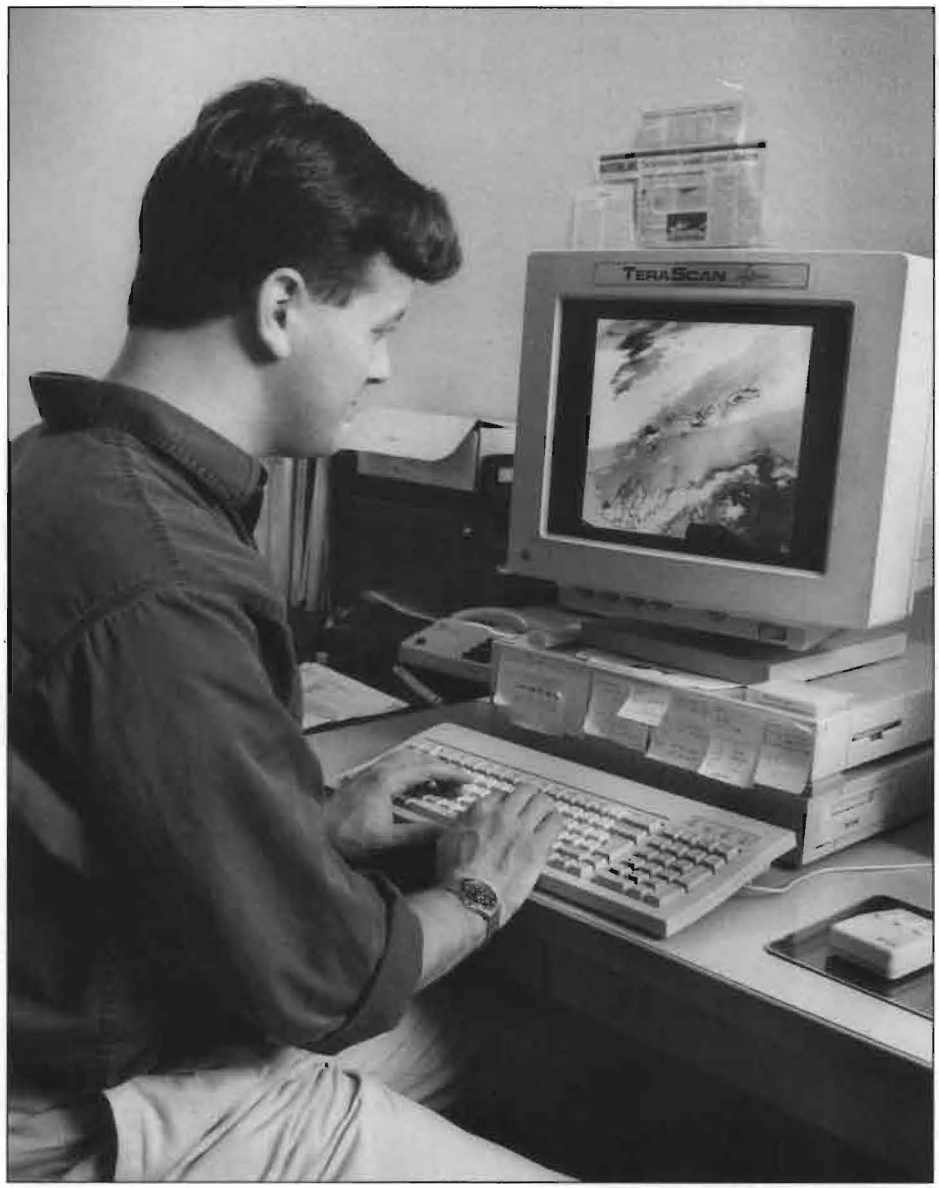
Antarctic Global Change Studies

The Antarctic has a profound influence on the earth's climate. Nearly 90% of the earth's fresh water is stored in the great ice sheets, which in conjunction with the seasonally variable sea ice create a planetary albedo gradient that affects the radiation budget of the entire atmosphere. Antarctic sea ice, which decreases from an area of more than 18 million to less than 4 million square kilometers between September and February of each year, is known to be sensitive to both shortwave and longwave radiative inputs. Knowledge of the atmospheric radiation budget over the Southern Ocean and extremities of the Antarctic continent is a key to understanding high-latitude climate change. The Antarctic coastline and Southern Ocean are among the cloudiest regions on earth, and are difficult to study with satellite data alone.

CalSpace researcher Dr. Dan Lubin conducted a successful four-month climate research program at Palmer Station, Antarctica. Dr. Lubin was joined by a CalSpace colleague and Robert H. Whritner from the Scripps Antarctic Research Center for part of the study. Palmer Station, on Anvers Island west of the Antarctic Peninsula, is an important location for sea ice and marginal ice

Research hut and spectroradiometer set up at Palmer Station in the Antarctic **(page 62).**

Dr. Dan Lubin at the Scripps Antarctic Research Center viewing satellite images of radiative cloud forcing over the Antarctic (below).



zone dynamics, however relatively few atmospheric science experiments have been conducted there.

The highlight of this field program was the successful deployment and operation of the CalSpace Fourier Transform Infrared (FTIR) spectroradiometer. This instrument can measure atmospheric emission in the wavelength region 500-2,000 cm^{-1} (5-20 μm) with a spectral resolution of 1 cm^{-1}. It can also record zenith radiances in the mid-infrared window region under a cold, clear Antarctic atmosphere, and gather an uninterrupted data set of more than 1,000 atmospheric emission spectra over the course of the field season. Preliminary data set analysis suggests that radiative cloud forcing measured at the Antarctic earth surface is up to three times larger than cloud forcing measured from space, emphasizing the importance of surface processes.

The CalSpace FTIR spectro radiometer also provides measurements of spectral cloud forcing—the wavelength dependence in the longwave radiative effect of clouds. Information collected will help ascertain the infrared emissivity and perhaps microphysical properties of Antarctic clouds. The data will also aid in the extrapolation of these measurements to large geographical areas by means of AVHRR satellite data, and the development of an Antarctic longwave radiation climatology for use by climate and sea ice modelers.

The southern oceans closely surrounding the Antarctic Peninsula are also a region of high biological activity. Each year during the austral spring and summer an enormous bloom in primary production takes place in these frigid waters. Primary production can be studied using remote sensing instruments and techniques that detect ocean color variations resulting from changes in phytoplankton pigment concentration. CalSpace scientist Dr. Robert J. Frouin is studying the optical properties—spectral, bidirectional, and polarization—of the solar radiation reflected by Antarctic waters and how they relate to water composition and primary production. He conducted an aircraft experiment in the Gerlache Strait and Marguerite Bay regions of the Antarctic Peninsula in December 1991. This was in support of a RACER (Research on

Palmer Station, all-sky cameras at left, satellite tracking antenna at right.

D. Lubin

Antarctic Ecosystem Rates) cruise. Surface pigment concentration and primary production were mapped in detail, thereby extending local ship observations. High and low altitude missions were flown with the French POLarization and Directionality of the Earth Reflectance (POLDER) instrument.

The data collected are being analyzed to verify innovative atmospheric correction schemes for ocean color remote sensing. They show that viewing the ocean surface from appropriate geometric and polarization angles substantially reduces the atmospheric contribution to the signal measured at high altitude (or even from space). Such viewing also enhances the relative contribution of the water-leaving radiance—the signal of interest in biological applications. This aircraft experiment points to new opportunities for Antarctic research.

During the RACER cruise, Dr. Frouin took POLDER measurements not only over water surfaces, but also over ice/snow and clouds, providing a unique data set (one of the few existing) on polarization characteristics of snow/ice and clouds. He found that these characteristics appear useful to discriminate between the two features, a problem when making satellite measurements over the polar regions. Ice/snow surfaces, unlike clouds, were observed to weakly polarize solar radiation. This spectral and bidirectional information will help improve estimates of light available for photosynthesis and for the surface radiation budget in this biologically active and climatically sensitive area.

CalSpace Mini-Grant Program

Support of space science and global change research through the disbursement of small awards to individual scientists is a major function of CalSpace. Their mini-grant program promotes research by awarding one-year grants for studies in the fields of space science and engineering, astronomy and astrophysics, satellite remote sensing, and global change. The program, open to all researchers in the UC system, provides seed money to test innovative areas of space-related research. During the 1991-1992 fiscal year, CalSpace awarded $621,979 to 40 investigators proposing high-quality and novel research.

The California Space Grant Consortium

CalSpace plays an important role in expanding educational opportunities for students in space science and engineering, and climate and global change. CalSpace is the designated headquarters and administrative arm of the NASA-sponsored California Space Grant Consortium. The consortium, comprised of UCB, UCLA, and UCSD, develops space science and engineering education from kindergarten to the graduate level. For more information write to:

State Space Grant Director 0524,
9500 Gilman Dr.,
La Jolla, CA 92093-0524,
or phone(619) 534-8959.

Institute of Geophysics and Planetary Physics

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

IGPP research at Scripps covers fields from global seismology to marine acoustics. This report is focused on geodetic monitoring of California tectonics and electromagnetic studies of the earth.

Earthquake Studies—
A Large Event Provides New Data

This year, the most exciting event for many IGPP scientists occurred at 5 A.M. on June 28, 1992, when California experienced its biggest earthquake in 40 years. This earthquake, centered in the sparsely populated Mojave Desert near Landers, California, was less destructive than the Loma Prieta, California, earthquake of 1989. The Landers earthquake was five times bigger (magnitude 7.5 instead of 6.9), and has already provided interesting data.

The cause of the earthquake was the breakage, over a distance of 70 km, of a series of faults, giving spectacular offsets of 3-6 m. The effects of this motion were detectable far from the fault. This was most notable on the Permanent GPS Geodetic Array (PGGA), operated by a consortium led by Dr. Yehuda Bock. The array uses satellites in the Global Positioning System (GPS) to measure the distances between antennas (separated by hundreds of kilometers) with an accuracy of several millimeters. This is the first time that continuous GPS tracking has detected the signal from a large earthquake. Analysis of the data by Dr. Joachim F. Genrich showed that the PGGA station at IGPP's Piñon Flat Observatory (PFO), over 70 km from the epicenter, has moved to the north by about 5 cm (2 inches); Scripps, 170 km away, moved

UCSD undergraduate student Stephen J. Dockter and Dr. Frank K. Wyatt set up a theodolite (page 65). Dr. Wyatt and Dockter use the theodolite to monitor precisely the displacements of geodetic reference marks (below).

about 2 cm. The PGGA stations are providing the basic framework for many instruments being used to resurvey the fault zone. Institute scientists also participated in these resurveys, which should give the most detailed record ever of slip on a major fault.

The Landers event was followed by another, much smaller (magnitude 6.5) shock at Big Bear, California a few hours later. Together these earthquakes outlined one of the parts of the San Andreas Fault that has been given a relatively high probability of rupturing in a great earthquake. In the immediate aftermath of these earthquakes there was great interest in any data that might indicate the possibility of a subsequent, catastrophic event. Because the Scripps laser strainmeters operated at PFO are by far the best sensors of slow motion on the San Andreas Fault, there was intense interest, by such groups as the California Earthquake Prediction Council, in the recordings from these instruments.

A detailed examination of these data by Drs. Frank K. Wyatt and Duncan C. Agnew showed a very interesting signal—a decaying exponential with a time constant of a few days. This is the first credible observation of postseismic motion on these time scales: from the standpoint of possible additional earthquakes it was very reassuring—the signal was slowing down rather than speeding up.

IGPP scientists also helped record many of the aftershocks of these earthquakes by setting up portable broadband seismic stations close to the fault. In this effort, Dr. Frank L. Vernon and colleagues used the advanced systems developed for seismic work in Kyrghyzstan. These systems promise to give a high-fidelity picture of the nature of these aftershocks and the structure on and around the fault. The high-fidelity Anza seismic network, also operated by Dr. Vernon, has already produced one important, although negative result: there was no increase in small earthquakes along the San Jacinto Fault (which parallels the San Andreas) following the Landers event. This is in strong contrast to the increase in small earthquakes in many more distant locations (as far as Mount Shasta) and suggests that these 'triggered' events might be different from the tectonic earthquakes seen at Anza.

The Electrical Conductivity of Mantle Rocks

To study the earth's interior scientists are constrained to work on its

surface. They are guided by observations of rocks that have been disgorged by emplacement and eruption processes. Geophysicists use a combination of field and laboratory studies to map and characterize the crust, mantle, and core of the planet. Outside of seismology, electromagnetism is the only technique in which natural sources of energy can be supplemented by man-made energy sources. Electromagnetic soundings of the earth's crust and mantle, using current-carrying coils or grounded wires, provide estimates of electrical conductivity. These are important because conductivity is highly sensitive to temperature and to trace materials on grain boundaries and in interstices. Examples of such materials are fluids (seawater and melt), ore minerals, and elemental carbon.

Scripps was one of the early users of geomagnetism and electromagnetic methods for probing the earth's interior, particularly the study of oceanic crust and mantle using seafloor experiments. A six-year collaboration between Dr. Steven C. Constable and colleagues at the national laboratories in Livermore and Los Alamos produced important data on the electrical conductivity of mantle materials.

The mineral olivine is the most significant constituent of the upper mantle; it is the major mineral in terms of volume, and its transport properties dominate the physical properties of the bulk mantle. Most silicate minerals are solid electrolytes that conduct electricity poorly (by moving charged ions as crystal-point defects—missing, interstitial, or substituted atoms). Olivine, $(Mg, Fe)_2SiO_4$, on the other hand, behaves as a semiconductor.

One type of iron ion, Fe^{+++}, can exist as a crystal defect at lattice sites normally occupied by a different iron ion, Fe^{++}. The extra charge can move through the crystal by 'hopping' from one Fe site to another. The mobility of this electron hole is much greater than vacancies or interstitial ions, making olivine more conductive than most other silicate minerals. The amount of Fe^{+++} is determined by the oxidation state of the mineral, rock, or mantle, so it is crucial in laboratory experiments to control the partial pressure of oxygen. Scientists also control experimental oxygen to keep the olivine from oxidizing to form magnetite and pyroxene or reducing to form elemental iron and pyroxene. Available oxygen is regulated by passing a calibrated mixture of CO_2 and CO gas through the apparatus. In this way free oxygen in the experimental atmosphere can be reduced to one part in 10^{24}, or about one molecule per 20 liters. The disadvantage of this gas mixing technique is that the experiment must be performed at atmospheric pressure. Fortunately, the pressure effect on olivine conductivity is thought to be secondary to the effect of temperature. The sample is heated in a furnace to temperatures as high as 1,600°C, while measurements of temperature, electrical conductivity, and oxygen partial pressure are made.

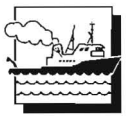
Previous studies of electrical conductivity focused on using samples cut from single crystals of olivine or crushed and sintered crystals, as these are much easier to handle than polycrystalline rocks. However, the application of the single-crystal measurements to mantle conditions was the subject of speculation. For example, common practice was to multiply conductivities determined for single crystals in the laboratory by ten in an attempt to account for the more complicated situation in the real earth. An initial study on a metamorphic dunite (monomineralic olivine rock) demonstrated that natural rocks could provide reproducible results in agreement with single crystal studies as long as oxygen partial pressure was controlled, and that trace minerals did not affect conductivity.

A second experiment was performed on a true mantle rock that had been erupted explosively from a depth of 40-80 km. This rock contains both olivine and pyroxene (a lherzolite) but has a conductivity near that of pure olivine. Although conductivity is dominated by olivine, the sample was, if anything, better behaved during the experiment than single crystals because the pyroxene and spinel in the rock buffered the activities of silica and iron. During the 1,700 hours in which the sample was held at a temperature above 600°C, its baseline conductivity drifted by only 30%. This relatively slow variation enabled an accurate study of the temperature effect on conductivity. Temperature variations cause the conductivity to vary by a factor of 3,000.

The data from many experiments have been pooled to provide a conductivity-temperature relationship for mantle rock, a finding that will have an impact on other work being done at Scripps. By combining this model with oceanic geotherms, upper mantle conductivity structure with depth can be predicted and included in the interpretation of both controlled-source and natural-source seafloor electromagnetic soundings. By combining the conductivity model with mid-ocean ridge thermal models derived from geodynamic calculations, seafloor electromagnetic experiments are being designed to maximize the resolution of ridge temperature and melt structure. Finally, upper mantle temperature and conductivity structure can be included in the modeling of global geomagnetic soundings, allowing stronger constraints to be put on the nature of conductivity structure 200-1,000 km deep in the mantle.

An expansion of laboratory and office space for IGPP is now under way. The extension to the present IGPP building has been made possible by the Cecil and Ida Green Foundation for the Earth Sciences. IGPP will gain office space for 27 faculty and research staff, 30 graduate students, 12 postdoctoral candidates, and several large laboratories and a classroom.

Captain Thomas J. Desjardins at the ship's control console on the navigation bridge of R/V *Melville*.



Research Fleet

One of the main tools in the study of the ocean is our oceanographic fleet, which is made up of four research vessels and two platforms. Our fleet traveled more than 72,558 nautical miles in fiscal 1991-1992 and operated at total of 727 days. The following charts briefly describe the areas of operations, work performed, and ports of call of this past year's expeditions.

R/V *Robert Gordon Sproul*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
6/29-7/4/91		North Pacific	Transit	Astoria		L. Zimm
7/5-8/6/91		Columbia River	Land margin ecosystem	Astoria	D. Jay (UW)	L. Zimm
8/7-8/11/91		NW Pacific	Transit	San Diego		L. Zimm
8/14-8/16/91		Southern California coast	Wave instrument installation	San Diego	R. Guza	L. Zimm
8/23/91		Southern California coast	Equipment testing	San Diego	S. Constable	L. Zimm
8/27-8/29/91		Southern California coast	Barophilic bacteria studies	San Diego	A. Yayanos	L. Zimm
9/17-9/25/91		Santa Monica Basin	Food chain	San Diego	F. Azam	L. Zimm
9/30-10/18/91		Año Nuevo	Sea lion studies	San Diego	B. LeBoeuf (UCSC)	L. Zimm
10/13-10/25/91		Southern California coast	Circulation of California Shelf	San Diego	C. Winant	L. Zimm
11/4-11/8/91		Southern California coast	Wave instrument installation	San Diego	R. Guza	L. Zimm
11/22-11/24/91		Offshore Del Mar	Class cruise	San Diego	P. Lonsdale	L. Zimm
11/24-11/27/91		Santa Barbara Basin	Clam collection	San Diego	D. Wilmot	L. Zimm
12/9-12/10/91		Southern California coast	Food chain	San Diego	F. Azam	L. Zimm
1/21/92		San Diego coast	Sea trial	San Diego		R. Price
1/31-2/1/92		San Clemente Basin	Towing dead whale	San Diego	C. Smith (U of HI)	R. Price
2/10-2/11/92		San Clemente Basin	Amphipod trap deployment	San Diego	A. Yayanos	L. Zimm
2/16-2/19/92		So. California coast and Santa Rosa Island	Wave instrument recovery	San Diego	W. O'Reilly	L. Zimm
2/29/92		Offshore San Diego	Student cruise	San Diego	R. Rosenblatt	L. Zimm
3/6/92		Offshore Del Mar	Equipment testing	San Diego	S. Winzer (Martin Mar.)	L. Zimm
3/10-3/12/92		Southern California coast	Sonar testing w/USS *Dolphin*	San Diego	S. Winzer (Martin Mar.)	L. Zimm
4/22-4/30/92		Southern California Bight	Mooring placement and recovery	San Diego	C. Winant	L. Zimm
4/30-5/1/92		Offshore San Diego	Water sampling	San Diego	H. Jeong	L. Zimm
5/10-6/20/92		Columbia River	Land margin ecosystem	Astoria	C. Simenstad (UW)	L. Zimm

TOTAL DISTANCE TRAVELED: 11,558 nautical miles **OPERATING DAYS:** 158

R/V *New Horizon*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
7/2-7/17/91		Southern California coast	FORAGE, MOCNESS	San Diego	J. Hunter (SWFC)	E. Buck
7/19/91		La Jolla	Services for R. Revelle	San Diego		E. Buck
7/20-7/25/91	Pulse VIII	Southern California coast	Benthic biology	San Diego	K. Smith	E. Buck
7/30-8/8/91	Pulse IX	Southern California coast	Benthic biology	San Diego	K. Smith	E. Buck
8/13-8/15/91	JOI-1	Southern California coast	Equipment testing	San Diego	F. Spiess	E. Buck
8/26-9/19/91		Juan de Fuca	OBS deployment w/FLIP	San Diego (Intermediate stop Newport)	L. Dorman	C. Johnson
9/21/91		San Diego	Upkeep	San Diego		E. Buck
9/28-10/14/91	CalCOFI	Southern California coast	Standard CalCOFI pattern	San Diego (Intermediate stop Pt. San Luis Obispo)	E. Renger	C. Johnson
10/19-10/28/91	Pulse X	Southern California coast	Bethnic biology	San Diego	K. Smith	E. Buck
11/2-12/3/91		So. California and Pacific	Water column survey	San Diego	J. Lupton (UCSB)	E. Buck
2/4/92		Off San Diego coast	Sea trial	San Diego		C. Curl
2/19-3/2/92	Pulse XI	Southern California coast	Bethnic layer sediment trap deployment and recovery	San Diego	K. Smith	C. Curl
3/9-3/12/92		San Pedro	MOCNESS tows and acoustic casts	San Diego	R. Pieper (USC)	C. Curl
3/14-3/28/92	FORAGE	Monterey Bay	MOCNESS net tows	San Diego	R. Dotson (SWFC)	C. Curl
5/8-5/22/92	TEFLON II	Pierdas Blancas	Landers deployment and recovery	Monterey	K. Johnson (Moss Land)	C. Curl
5/24-5/31/92	SU 92-2	Monterey Bay	CTD and net tows	Monterey	R. Dugdale (USC)	C. Curl
5/31-6/2/92		Monterey to San Diego	Transit	San Diego		C. Curl
6/6-6/14/92	ZB2	South of San Miguel Island	Drifter deployment and recovery	San Diego	M. Ohman	C. Curl

TOTAL DISTANCE TRAVELED: 16,914 nautical miles **OPERATING DAYS:** 187

R/V *Thomas Washington*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
7/16-8/25/91	TUNES II	Central South Pacific	WOCE P17c, P16	Papeete	J. Swift	A. Arsenault
8/31-10/1/91	TUNES III	150°W	WOCE P16	Honolulu	L. Talley	T. Desjardins
10/5-10/11/91	TUNES IVA	Loihi Seamount	Tiltmeter	Kawaihae	S. Constable	T. Desjardins
10/13-10/16/91	TUNES IVB	Off the island of Lanai	Rock drill tests	Honolulu	H.P. Johnson (UW)	T. Desjardins
10/18/91			USCG Inspection	Kwajalein		T. Desjardins
10/22-10/30/91	TUNES V		Transit	Kwajalein		R. Haines
10/30-12/1/91*	TUNES VI	Magellan Strait	Sea Beam and gravity	Guam	H. Staudigel	R. Haines
12/5-12/26/91*	TUNES VII	Mariana Trough	Sea Beam	Guam	S. Bloomer (Boston U)	A. Arsenault
1/1-2/1/92*	TUNES VIII	22°N 150°E, 10°N 171°E	Sea Beam and deep tow magnetic surveys	Majuro	H.P. Johnson (UW)	A. Arsenault
2/3-2/27/92	TUNES IX	Wake Island	Sea Beam and seismic survey	San Diego	P. Lonsdale	A. Arsenault
3/2-5/8/92	ENCORE I	Hess Deep	Seismic operations	Manzanillo	L. Dorman	A. Arsenault
5/9-5/13/92	ENCORE II	En route to San Diego	Sea Beam and airgun	San Diego	P. Lonsdale	A. Arsenault
6/19-6/23/92	JANUS	Southern California	Testing of new deep tow	San Diego	F. Spiess	A. Arsenault

*Cross International Date Line, however, dates shown represent U.S. date.

TOTAL DISTANCE TRAVELED: 37,353 nautical miles **OPERATING DAYS:** 274

R/V *Melville*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
3/17-4/3/92		Amelia, LA to San Diego	Transit	San Diego		T. Desjardins

TOTAL DISTANCE TRAVELED: 4539 nautical miles **OPERATING DAYS:** 18

R/P FLIP

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
7/10-7/18/91	OP-184	Off coast of San Diego	Difar array test	San Diego	G. D'Spain	*D. Efird
8/21-10/31/91	NOBS OP-185	Northern Gorda Ridge	Surface wave field study	San Diego	J. Hildebrand	*D. Efird
1/11-2/5/92	OP-186	Off coast of San Diego	Expedition for UW	San Diego	P. Dahl (UW)	*D. Efird

TOTAL DISTANCE TOWED: 2,194 nautical miles (drifting or under tow) **OPERATING DAYS:** 90 (moored, drifting, or under tow)
* OFFICER-IN-CHARGE OF FLOATING PLATFORM

R/P ORB

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN

TOTAL DISTANCE TOWED: 0 nautical miles **OPERATING DAYS:** 0

Research Vessel Statistics

	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	85.04 m	51.8 m	38.1 m	63.65 m	108.2 m	21.0 m
BEAM	14.02 m	10.97 m	9.75 m	12.1 m	6.0 m	13.7 m
DRAFT	5.02 m	3.85 m	2.59 m	4.77 m	3.4/91.4 m	fwd 1.5 m aft 1.6 m
DISPLACEMENT FULL (metric tons)	3,005.32	1,097.28	532.38	1,383.79	711.2	335.28
CRUISING SPEED (knots)	12	10	9.5	10	varies*	varies*
RANGE (nautical miles)	14,100	7,500	3,800	8,200	varies*	varies*
CREW	23	12	5	23	5	5
SCIENTIFIC PARTY	35	17	14	22	11	11

FISCAL 1991-1992 TOTAL NAUTICAL MILES TRAVELED: 72,558 **TOTAL OPERATING DAYS:** 727 *Depends on towing vessel

R/V *Melville* crewmen at work: (below), Tony P. Santos and Kelly Murgotten; (right), Charles Eckerson in the radio shack; (bottom), main deck of R/V *Melville.*

R/V *Melville*

by George G. Shor, Jr.

R/V *MELVILLE* IS NOW LONGER, stronger, faster, quieter, and more stable. This ship returned to full service in mid-summer of 1992, a very different ship from the one that entered the McDermott shipyard in Amelia, Louisiana, in September 1989, for a midlife refit. As rebuilt, *Melville* has twice the laboratory space, berthing for a larger scientific party (35), new main and auxiliary engines, a different propulsion system, a new electrical system with greater capacity, longer endurance (days) at sea, higher speed (12 knots cruising speed instead of 10), an antiroll system that really works, dynamic positioning, and a wide-swath bathymetric mapping system. The ship is much quieter acoustically than before, and is 10 m longer to accommodate all the changes. It is without doubt the best and most versatile ship in the University National Oceanographic Laboratory System fleet.

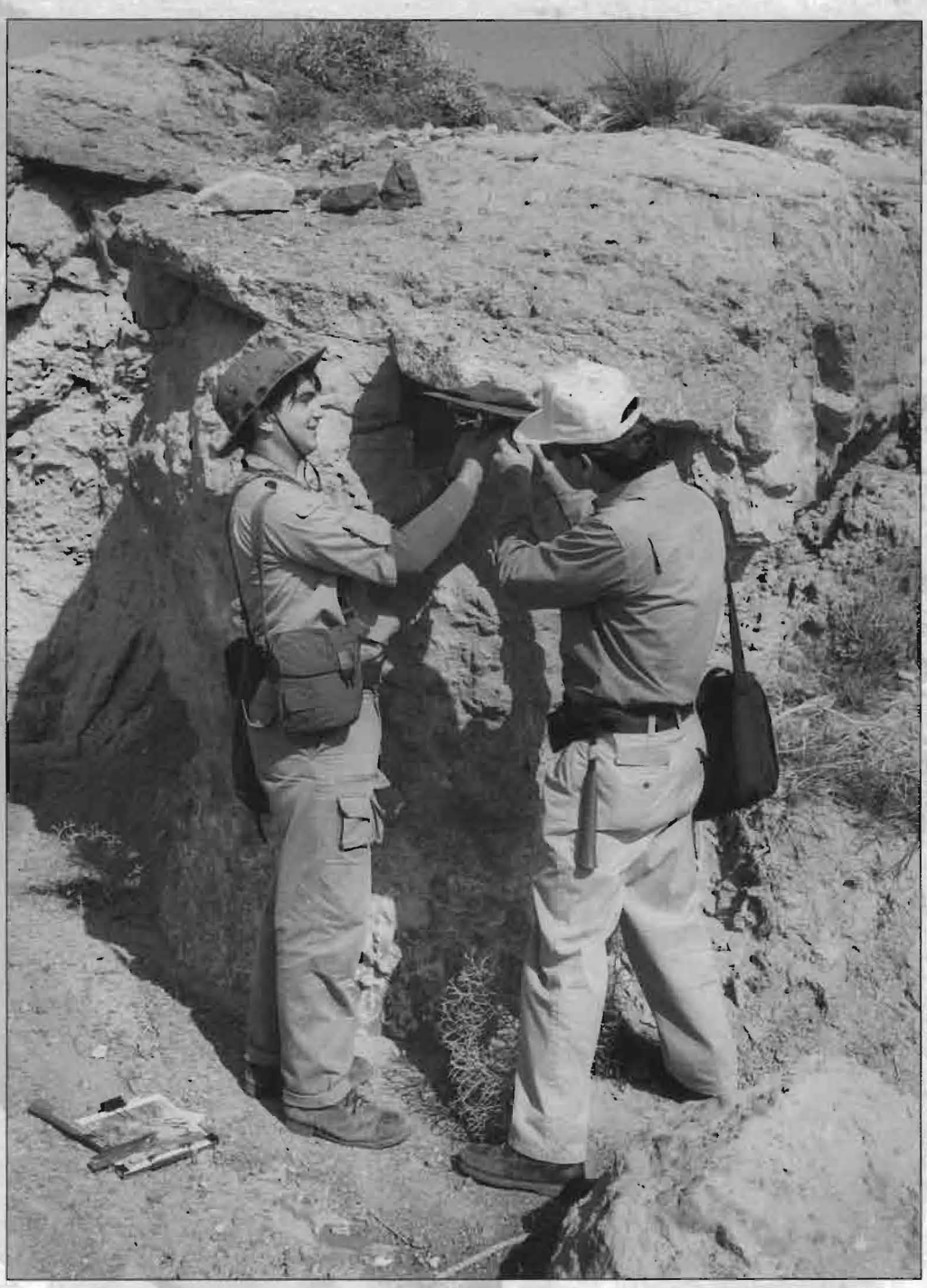
Melville entered service in 1969, and contained a number of unusual features, some of which made it a great ship—and some of which were its 'Achilles heels'. The ship had a single large, slow-speed main engine (of a type with a history of many decades of operation per engine). It had cycloidal propellers fore and aft, so it held position with precision, turned on a dime, and could move sideways. *Melville* had more laboratory space than any other academic research ship except its Woods Hole Oceanographic Institution (WHOI) sister-ship R/V *Knorr*. On the down side, the cycloids generated so much noise in the water that most types of work using underwater acoustics were nearly impossible. The aft cycloid was a 'prototype' that broke down frequently. The shaft driving the aft cycloid would not stay aligned. As the years passed the main engine parts were available only on special order, sometimes requiring six months for delivery. For a while, the parts were swapped between *Knorr* and *Melville*, but it was clear that something drastic must be done. Fortunately, the Secretary of the Navy volunteered funds for a major refit of both ships.

A committee representing the two institutions started planning for the reconstruction in the summer of 1985. Committee members made plans to cure the problems and add the technological capabilities needed for future oceanographic work. Their first priorities were reliability and flexibility—multiple engines with electric drive should replace the old engine. These new engines, generators, and rectifiers required more engine-room space, which could only be provided by lengthening the ships. This lengthening allowed more fuel capacity below, and more laboratory and berthing space above. To reduce the water noise while retaining the magnificent maneuverability, cycloids were replaced by Z-drives. These are three gigantic 'inboard-outboard' motors (two in fixed location at the stern, one retractable drive near the bow). While the response to the helm is not quite as fast, the ability to drive sideways, turn on a dime, and hold position on station is unchanged, and addition of a 'dynamic positioning system' has automated these tasks.

Enlargement of laboratory, living, and mess-hall space was needed for current 'major national programs'. There are two 'hanger' laboratories that are two decks high to accommodate large instrument packages, two large cranes to get these monsters over the side, a new J-frame to add to the two A-frames, a new 'controlled-environment' laboratory, and a new darkroom. There is an integrated electrical system, so propulsion power can also provide electricity for deck equipment and almost unlimited AC power. Crowning it all is the installation on *Melville* of a new multibeam echosounder, the Sea Beam 2000/SIO system (funded by the Keck Foundation and specially designed for us), which can map a strip of seafloor 15 km to 22 km wide (contouring a strip 90° wide to 11 km water depth, 120° wide to 4.5 km depth, plus a side-scan image 120° wide at all depths).

Melville and *Knorr* went through this reconstruction together, and we agreed to have WHOI manage the refit contract because a single management center was needed. *Knorr* went first despite being the younger ship (*Melville* actually used engine parts stripped from *Knorr* to make it to the yard). Robertson Dinsmore (Scripps alumnus and WHOI staff member) was appointed project manager for both ships, and was assisted by the marine facilities staffs and shipyard teams from both institutions. Chief Engineer Bob Fish headed our yard team through most of the prolonged period of work.

This reconstruction transpired with many headaches; a task that was to take 12 months took 33 months and an act of Congress to complete. Misunderstandings were numerous, and questions about costs are not yet settled. However, everything works well. *Melville* is a far better ship than before, and should continue to serve the oceanographic community for years to come.



Student Miguel A. Moreno and Dr. Paterno R. Castillo measure attitude of a bedding plane at Fossil Canyon during a field geology course.

Curricular Programs

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

University of California, San Diego, Scripps Institution of Oceanography, Graduate Department 0208, 9500 Gilman Drive, La Jolla, California 92093-0208.

Applied Ocean Sciences

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

Biological Oceanography

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

Geochemistry and Marine Chemistry

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

Geological Sciences

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

Geophysics

This curriculum educates the student about the physics of the solid earth, including the earth's magnetic field, the mechanics of tectonic processes, earthquakes and the waves they produce, the physics of the earth's interior, and mathematical methods for analyzing data and interpreting them in terms of models of the earth. The program emphasizes physical and mathematical approaches to geophysical research.

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 biomechanics, evolution, behavior, neurobiology, developmental biology, and comparative physiology/biochemistry.

Physical Oceanography

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

Student Enrollment

In the fall of 1991, 39 new students were admitted to graduate study. Of these, 10 were in marine biology, 3 in geological sciences, 2 in geochemistry and marine chemistry, 6 in geophysics, 6 in physical oceanography, 7 in applied ocean sciences, and 5 in biological oceanography. Enrollment at the beginning of the academic year was 178. UC San Diego awarded 22 Doctor of Philosophy degrees and 6 Master of Science degrees to the students listed in this section.

Graduate Students and Degree Recipients

Doctor of Philosophy Degrees Awarded, with Titles of Dissertations

Earth Sciences

Catherine D. de Groot-Hedlin, "Occam2: Regularized Inversion to Generate Smooth, Two-Dimensional Resistivity Models from Magnetotelluric Data."

Jeffrey S. Gee, "Some Aspects of Seamount Magnetization."

Joachim F. Genrich, "Geophysical Applications of GPS Kinematic Techniques."

Philip T. C. Hammer, "Seamount Structure from Seismic Tomography and Gravity Inversion."

Michael A. H. Hedlin, "Analysis of Seismic Coda to Identify Regional Sources and Image Strong Crustal Scatterers."

Mary E. Kappus, "A Baseline for Upper Crustal Velocity Variations along the East Pacific Rise."

Jennifer S. Scott, "Microearthquake Studies in the Anza Seismic Gap."

James M. Stevenson, "Some Applications of Marine Gravimetry to Mid-Oceanic Spreading Centers and Volcanos."

Rudolf Widmer, "The Large-Scale Structure of the Deep Earth as Constrained by Free-Oscillation Observations."

Marine Biology

Teodora U. Bagarinao, "Sulfide Tolerance and Adaptation in a Salt Marsh Resident, the California Killifish *Fundulus parvipinnis* Girard, and Other Shallow-Water Marine Fishes."

Frank J. Cynar, "The Biogeochemical Cycling of Methane in the Upper Ocean off Southern California."

Lee J. Kerkhof, "Developing a Species Specific Growth Rate Assay for the Marine Bacterium, *Pseudomonas perfectomarina*."

Alexander B. P. Leonard, "The Biomechanics, Autecology and Behavior of Suspension Feeding in Crinoid Echinoderms."

Wendy L. Ryan, "An Analysis of the Role of Hydrophobic Surfaces and Crevices in Bubble Formation at Low Gas Supersaturation."

Jeffrey L. Stein, "Molecular Genetics and Biochemistry of Ribulose-1,5-Bisphosphate Carboxylase/Oxygenase in the Endosymbiont of the Hydrothermal Vent Gastropod *Alvinoconcha hessleri*."

Oceanography

Philip S. Bogden, "The North Atlantic Circulation: Combining Simplified Dynamics with Hydrographic Data."

Haiyin He, "Studies of Biologically Active Natural Products from Marine Invertebrates."

Juan C. Herguera, "Paleoproductivity and Deep-Sea Circulation Changes during the Late Quaternary: Evidence from the Western Equatorial Pacific."

Tong-Sup Lee, "Cosmogenic 32P and 7Be Used as Tracers for Phosphorus Biogeochemistry in the Upper Ocean."

Mathew E. Maltrud, "Structures, Spectra and Inertial Range Transfer in Two-Dimensional and Beta-Plane Turbulence."

John E. Mak, "The Isotopes of Carbon Monoxide in the Free Troposphere and Their Implications to Atmospheric Chemistry."

Duane E. Waliser, "The Preferred Latitudes of the Intertropical Convergence Zone: Observations and Theory."

Master of Science Degrees

Earth Sciences	Oceanography
Dalia Lahav	Broderick V. Berkhout
Han-Xing Liu	Shirley M. Isakari
Valerie J. Scruggs	Nghi T. Nghiem

Ungraded site of the Stephen Birch Aquarium-Museum, the Scripps campus in background.

Shore Facilities

Many of the facilities and collections at Scripps are used both for teaching and research. Several of these facilities are also available to those outside the Scripps community either for a fee or for free.

Each facility and collection is described briefly in this section. For more information please write directly to the specific facility or collection in care of Scripps Institution of Oceanography.

Every year one of these facilities or collections is described in photos. This year the construction of the Stephen Birch Aquarium-Museum is featured through out this section.

Analytical Facility

Instruments at the facility include a Philips automated x-ray fluorescence spectrometer with computerized control and data analysis; three x-ray diffraction systems, including a Philips APD 3600/02 with computer-aided search/match mineral files; a Perkin Elmer Zeeman/5000 atomic absorption/fluorescence spectrometer with heated graphite, furnace auto sampler, and metal hydride systems; a Hewlett-Packard 5988 computerized GC/mass spectrometer and four H/P gas chromatographs with EC, FI detectors; a Perkin Elmer HPLC with multicolumn capability and fluorescence; diode array detectors; a superconducting IBM nuclear magnetic resonance spectrometer with an aspect 3000 color graphics system; a Coulometrics total carbon/CO_2 analyzer; a P/E model 2400 CHN analyzer; a P/E FT infrared spectrometer; a P/E UV-VIS Lambda 3B spectrometer; a Cambridge 360 scanning electron microscope with a Link energy-dispersive x-ray spectrometer and image analysis system; a Hitachi H-500 scanning transmission electron microscope with an Ortec EDS x-ray spectrometer; a Zeiss 9 TEM; diamond knife microtomes; a Cameca 'Camebax' electron microprobe with three automated crystal spectrometers, polarized light optics, SEM, TEM capabilities, Ortec EDS x-ray system; a Canberra/DEC computer system; a VG instruments ICP/MS with electrothermal vaporization and laser ablation techniques; and a Finnigan MAT 252 gas mass spectrometer with eight collectors.

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

Aquarium Facilities

There are two research aquarium facilities; each is provided with a dual-line system that delivers seawater at ambient temperatures. The Ritter Hall Experimental Aquarium (250 m^2) is equipped with 5 rooms for controlled experiments, 20 tanks with capacities from 425 to 5,000 liters, 9 seawater trays, limited counter space, and two sinks. A single-line, noncirculating chilled seawater system delivers approximately 150 liters per minute at 10°C. The Marine Biology Aquarium (280 m^2) is equipped with 28 tanks with capacities from 750 to 1,500 liters, 18 seawater trays, counter space, and sinks. Two chilled seawater systems deliver approximately 150 liters per minute at temperatures of approximately 2°C and 8°C in the winter and 4°C and 15°C in the summer.

Cardiovascular Research Facility

This facility, shared by the Physiological Research Laboratory and the UC San Diego School of Medicine, contains the analytical equipment needed for measuring circulatory and cardiac functions in conscious, unrestrained animals, and an instrumentation development laboratory.

Diving Facility

The Scripps Research Diving Program is the oldest of its type in the country. The scientific diver training and certification program is nonrecreational and is offered to those who need to dive for their work or studies. Each department must indicate that an applicant cannot function satisfactorily as an employee or student without obtaining diving certification. The SCUBA class is a two-week program.

The research diving program is administered by a control board comprised of the senior research diver in each Scripps department. The diving locker housing the air compressors, filter bank, diver air cylinder storage, equipment repair facility, and the shower and wet locker storage is operated under the program. These facilities are available to university certified research divers.

On an average 110 faculty, staff, and students participate in this program yearly. An average of 3,600 dives has led to an accumulation of nearly 200,000 dives over a 30 year period throughout the world's many aquatic environments.

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

Ellen Browning Scripps Memorial Pier
The 320-m pier serves as a launching site for small boats used for local oceanographic work, provides space for nearshore studies and tide gauge and weather recordings, sampling, and supports the seawater system that supplies the aquaria and laboratories.

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

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

Tide pool exhibit foundations are poured, construction of the Stephen Birch Aquarium-Museum in background.

Kendall-Frost Mission Bay Marsh Reserve
(Mission Bay, San Diego)
Approximately 50 acres of Mission Bay marshland (16 acres university-owned) constitute a marsh preserve and wildlife refuge designated for teaching and research. The reserve is the last fragment of the once extensive Mission Bay salt marsh. This property is one of 32 natural reserves used for teaching and research in the University of California Natural Reserve System. A small laboratory is located on the preserve. For more information write to:

University of California, San Diego, Reserve Manager, UC San Diego Natural Reserve System, Scripps Institution of Oceanography 0201, 9500 Gilman Drive, La Jolla, California 92093-0201.

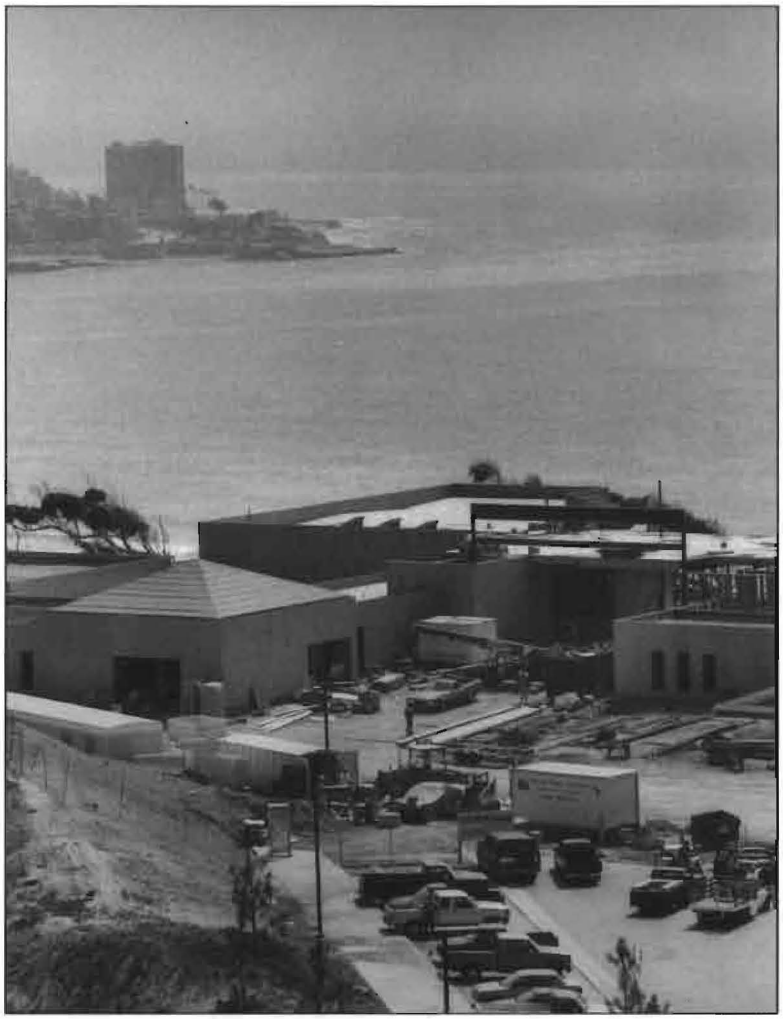
Marine Science Development and Outfitting Shop
This shop is equipped with precision tools and machinery. A staff of toolmakers and diemakers designs and fabricates research equipment and instrumentation for various Scripps laboratories and

other educational and governmental organizations throughout the United States.

Mass Spectrographic Equipment
Ten mass spectrometers are available: two 15-cm, Nier-type spectrometers, and one Finnigan MAT 252 instrument for isotopic analysis of light elements; a 15-cm, Nier-type spectrometer for rare gases; a 25.4-cm double-collection mass spectrometer for He^3/He^4 ratio measurements; a Hewlett-Packard 5988 gas chromatograph-quadrupole mass spectrometer for qualitative separation and analysis of organic compounds; a 30-cm-radius, solid-source mass spectrometer for geochronology and isotope dilution analysis; a small, portable, helium mass spectrometer for field use; a Finnigan stable isotope mass spectrometer for the analysis of gases; and a 3-cm mass spectrometer for stable isotope tracer measurements.

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 three inter-connected holding pools for marine mammals and fishes. One pool is a 10-m radius ring equipped with a variable-speed trolley to carry instruments for hydrodynamic and biological studies of swimming subjects. The central island laboratory within this ring consists of two small, 'dry' rooms and a 'wet' area featuring a connecting channel for the transfer of animals from the ring pool into the laboratory.



Stephen Birch Aquarium-Museum near completion.

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

Scripps Coastal Reserve
The reserve is situated just north of La Jolla, and is comprised of two disjunct portions. The shoreline portion, adjacent to Scripps, consists of intertidal rocky and sandy beach, and a subtidal component that extends 1,000 m seaward to include the head of one branch of the Scripps submarine canyon and a 320-m pier. This area is directly north of the San Diego-La Jolla Ecological Reserve of the California Department of Fish and Game.

The upland areas are collectively called the 'Knoll', and consist of two coastal canyons, the bluff top between them, and 100 m high steep sea cliffs. Several important archeological finds have been made at the Knoll, which also protects a number of coastal habitats, flora, and fauna considered sensitive or endangered by the state.

Scripps Library
With outstanding collections in oceanography, marine biology, and marine technology, in addition to extensive resources in atmospheric sciences, ecology, fisheries, geology, geophysics, and zoology, the Scripps library is one of the largest marine science libraries in the world. The library currently receives more than 3,700 serial titles and has more than 225,000 volumes, including an extensive collection of technical reports and a rare book collection featuring accounts and journals of famous voyages of scientific discovery. A large map collection contains bathymetric, geologic, and topographic maps and charts of world areas and oceans.

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

Scripps Satellite Oceanography Center (SSOC)

This facility enables oceanographers to receive and process satellite imagery. Data transmitted in real time by the NOAA polar orbiting satellites are received by the 5-m tracking antenna. 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. During early 1990 the old Scientific Atlanta orbital tracker was replaced and other antenna upgrades were made. A new UNIX-based capture system, consisting of an HP 9000/370 work station, new bit and frame synchronizer was installed. Data are now archived on magneto-optical disk and/or DAT tape. Capture is fully automated and different S or L band data passes can be intermixed in the collection process.

A new user's center was opened and a UNIX-based image analysis work station is available for general image processing. This system consists of a dedicated HP 9000/380 work station with 16 Mbytes of RAM and 1 Gbyte of magnetic disk. The 660 Mbyte multiple read, multiple write magneto-optical disks, DOS-Partition, HP 7980 1600/6250 streaming tape drive, 24-bit plane image display, and a precision camera are interfaced to this user machine for executing digital image analysis applications. A separate terminal room is available for software development by center users.

A new HP 9000/380 work station with magneto-optical autochanger capability (presently 28 Gbytes and expanding) has been installed for archiving all AVHRR data taken by SSOC since 1979. An on-line digital browse and automatic data ordering system using X Window protocols has been developed for use with this system. Since completion (August 1991), this system has provided world-wide access to SSOC data bases via national and international computer networks. Current applications include near-real-time support of research vessels and aircraft with remotely sensed images to detect phenomena of interest for their in situ observation programs. Other activities include determination of sea-surface temperature anomalies, retrospective analysis of image data sets in relation to physical and biological oceanography studies, real-time support of fishing fleet operations and cloud/radiation studies to investigate global change processes. It is anticipated that GEOSAT altimeter and GOES data also will be processed on the new systems. Four-day courses are frequently taught to give potential users an overview of the available tools and hands-on experience. Advanced programing and digital image analysis courses also are offered on a periodic basis.

The kelp forest exhibit window, California's largest acrylic viewing window, being readied for placement by a giant crane.

Seawater System

Pumps located on the seaward end of Ellen Browning Scripps Memorial Pier deliver seawater to the laboratories and aquaria of Scripps and the National Marine Fisheries Service. The raw seawater is filtered through three, 180-cm-diameter, high-speed sand filters and pumped up into two concrete storage tanks with a total capacity of approximately 450,000 liters. Water flows by gravity to the public aquarium and Scripps research laboratories, while approximately 750 liters per minute are pumped up to the National Marine Fisheries building. The system is capable of delivering a maximum of 7,200 liters per minute.

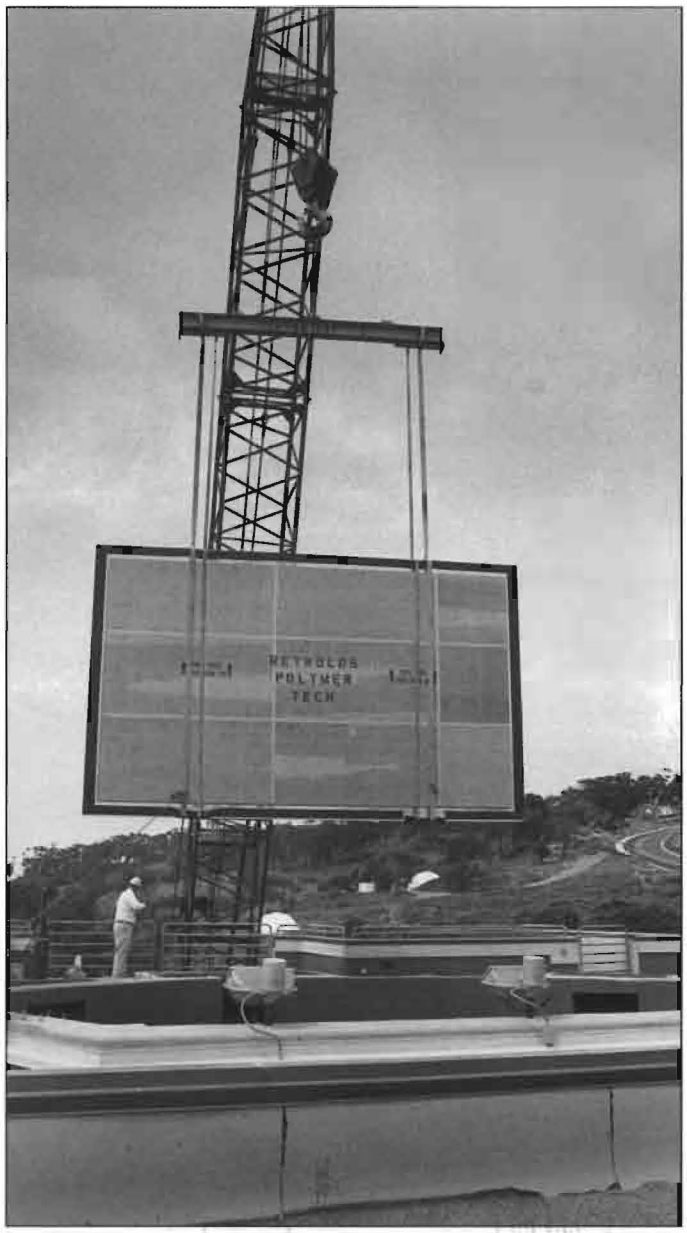
Shipboard Technical Support

Shipboard Technical Support is an amalgamation of several groups that serve both Scripps and the oceanographic community at large. The group provides technical and data-collection services aboard Scripps's research vessels, supplying and maintaining shipboard scientific facilities (computers and geological, biological, physical, and chemical data-acquisition systems); logistic support for these facilities; and postcruise data processing, distribution, and archiving. Shipboard Technical Support also furnishes data collection equipment and highly trained technicians for University National Oceanographic Laboratory System (UNOLS) ships and international programs.

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

The Shipboard Computer Group is composed of 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 730s on the ships. These computers are installed permanently on R/V *Thomas Washington* and R/V *Melville*, and they are interfaced to navigational and scientific instruments, including the R/V *Thomas Washington* Sea Beam system.

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



The 6.4-m wide, 4-m high, 25.9-cm thick acrylic window being lowered into place for the kelp forest exhibit tank.

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

Technicians in the ***Oceanographic Data Facility (ODF)*** participate in oceanographic expeditions for investigators from Scripps and other institutions. ODF can provide only equipment or equipment and technicians for large operations involving several types of over-the-side activities. ODF technicians (from one to ten per cruise) have participated in many recent multi-institutional expeditions.

ODF usually provides electronic profiling of the water column including acquisition and processing, and salinity, oxygen, and nutrient analyses and data processing, with occasional expeditions requiring large-volume sampling and radiocarbon extractions. 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 that supports both shipboard and shore-based processing, including real-time processing of CTD data. Electronics design work for many different applications is done routinely. The ODF on-site shop and laboratory facilities are augmented by the testing facilities at the Scripps Hydraulics Laboratory, and other Scripps facilities.

ODF seagoing technicians and data specialists may be loosely grouped into serial data (CTD) specialists, chemical analysts, marine technicians, and electronic technicians. ODF technicians continue to develop more economical methods that benefit smaller or limited-operation expeditions.

SSURF: SIO Supercomputer Users Remote Facility

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

SSURF is a VAX 3400 computer running both VMS and UNIX operating systems. Connected to SSURF is an array of plotters, printers, tape drives, and over 2 Gbytes of disk storage. The SSURF computer center services are available 24 hours a day year-round.

Thomas Wayland Vaughan Aquarium-Museum

The aquarium-museum is the interpretive center for Scripps Institution of Oceanography. Its goals encompass increasing public understanding of the ocean environment, promoting wise use of global resources, and generating support for marine research. The facility features museum exhibits on oceanographic topics, a variety of educational programs, and displays of living marine animals from California, the Gulf of California, and the western tropical Pacific. This year more than 364,000 people visited the facility including 31,800 students in educational groups. The aquarium-museum is open to the public daily from 9:00 A.M. to 5:00 P.M.

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

Workers seal the large acrylic window for the kelp forest exhibit.

A new aquarium-museum, to be named Stephen Birch Aquarium-Museum in honor of the major donor, is nearing completion and will open in September 1992. The new facility will be three times larger than the present one and includes an education center and substantial visitors parking lot. Visitors will enjoy 34 aquaria, including a 265,000-liter representation of the La Jolla kelp forest; a demonstration tide pool; a changing gallery with an inaugural exhibition of underwater photography; and a new permanent exhibition on the ocean sciences, *Exploring the Blue Planet*, funded in part by a $500,000 grant from the National Science Foundation. The project is expected to cost approximately $10.5 million, exclusive of parking and roads.

Friends of the Aquarium, the aquarium-museum public membership group, offers ocean-related activities to its members including local field trips, lectures, family activities, and collecting expeditions. As part of the SIO Associates, Friends of the Aquarium receive a bi-monthly calendar and a quarterly newsletter.

Special Collections

Benthic Invertebrates
The collection contains some 50,000 lots of specimens sorted into major taxonomic groups such as Coelenterata, Echinodermata, Crustacea, and Mollusca. All are accessioned with collection data, and more than 35% are identified to species. Specimens, several catalogs of holdings (Decapod and Stomatopod Crustacea, Brachiopoda, and Echinodermata), and IBM-compatible dBase IV catalog data for various groups are available to qualified students and researchers.

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

Geological Data Center
The Geological Data Center provides at-sea data processing and on-shore processing, distribution, and archiving of underway marine geophysical data. Navigation, depth, magnetics, gravity, and Sea Beam data are computer-processed for entry into the digital database and for production of cruise reports and plots. A multidisciplinary index of all samples and measurements made on major Scripps cruises is maintained by the data center. Charts and other geophysical data sets are also available.

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

Marine Invertebrates
Included in this collection of more than 80,000 documented whole zooplankton samples are accessioned holdings from expeditions, the continuing CalCOFI program, and special projects. Samples represent zooplankton collected with nets, ranging from surface neuston to bathypelagic midwater trawls. The major emphasis of the collection has been in the northeastern Pacific, but an increasing number of samples are also available from other oceanic and continental slope regions. The collection includes identified specimens for some of the major taxonomic groups. Most samples are supplemented with physical and chemical data.

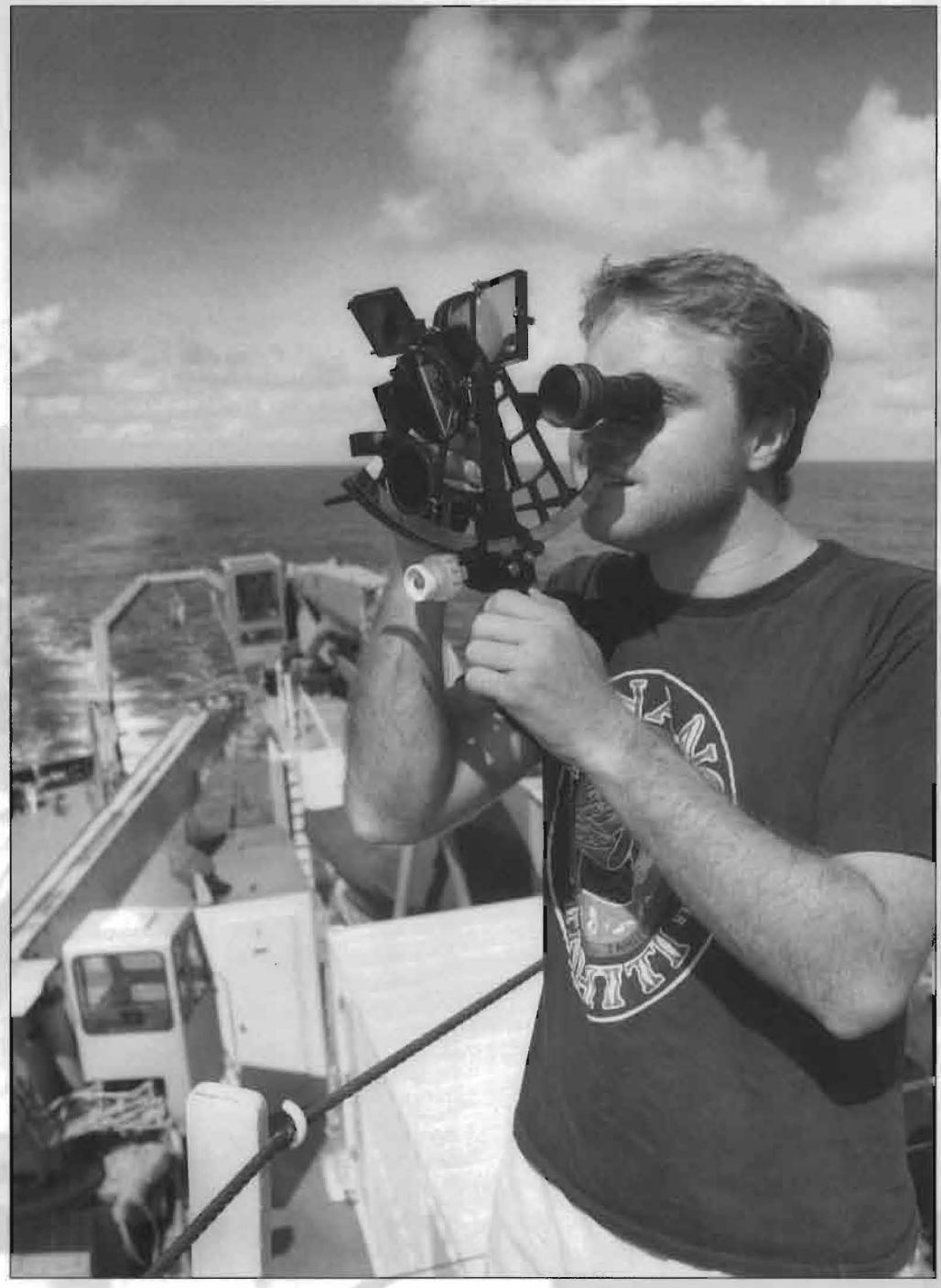
Marine Vertebrates
This collection contains approximately 2.5 million specimens, with more than 4,500 cataloged species, including 170 primary types. About 200 collections are added each year. Although the collection is worldwide, deep-sea and pelagic fishes and eastern Pacific shorefishes are emphasized. Included are large holdings of shorefishes from the Gulf of California and Panama, and an extensive skeletal collection of dried preparations and cleared-and-stained specimens in glycerin, with more than 700 species represented. The otolith collection contains otoliths from approximately 500 species.

Oceanographic Data Archives
Tide-gauge records have been taken daily from the Scripps Pier since 1925. Monthly tide-gauge records from 1947 to 1967 and from 1980 to the present are available in the Scripps Library archives. Records before 1947 and from 1967 to 1980 can be obtained by writing the Chief of the Datums and Information Branch, N/OMA 123, NOAA/NOS, 6001 Executive Blvd., Rockville, MD 20852.

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

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

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



Wesley Hill uses a sexton to take a sunline aboard R/V *Melville*.

APPENDIX A

Publications

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

A listing of recent Scripps publications follows. Detailed information on the availability of each series is included.

Bulletin

The *Bulletin of the Scripps Institution of Oceanography* is an irregularly published series for lengthy, in-depth scientific papers written by Scripps scientists. For information about subscriptions and a list of volumes available please write to **University of California Press, 2120 Berkeley Way, Berkeley, California 94720.**
The most recent volumes are listed below.

v.27 **Wilson**, George D. F. A Systematic Revision of the Deep-Sea Subfamily Lipomerinae of the Isopod Crustacean Family Munnopsidae. 1989. 138p.

v.28 **Castellini**, Michael A., Randall W. **Davis** and Gerald L. **Kooyman**. Annual Cycles of Diving Behavior and Ecology of the Weddell Seal. 1992. 54p.

CalCOFI Publications

The work of the California Cooperative Oceanic Fisheries Investigations (CalCOFI), in which the Scripps Institution of Oceanography, the California Department of Fish and Game, and the National Marine Fisheries Service cooperate, is published in a variety of formats. Peer-reviewed scientific articles are published annually in the *California Cooperative Oceanic Fisheries Investigations Reports*. Maps of physical, chemical, climatological, and biological factors measured by CalCOFI researchers during the program's 43-year history are published irregularly in the *California Cooperative Oceanic Fisheries Investigations Atlas* series. Data reports, containing the processed data from specific cruises carried out under CalCOFI sponsorship, are published irregularly in the SIO reference series and in the CalCOFI data report series. To obtain copies of any of these CalCOFI publications, write to **University of California, San Diego, Scripps Institution of Oceanography, CalCOFI Coordinator 0227, 9500 Gilman Drive, La Jolla, California 92093-0227.**

Contributions

The *Scripps Institution of Oceanography Contributions* is a compilation of selected reprints authored by the Scripps faculty and staff. This annual publication is available ONLY on an exchange basis to other scientific, research, and educational institutions. For exchange information please write to **University of California, San Diego, Scripps Institution of Oceanography, Library Exchange Department 0175-C, 9500 Gilman Drive, La Jolla, California 92093-0175.**

The articles listed below were published in the 1991 volume and may also be found in the publications cited. Information about a specific reprint can be obtained by writing directly to the author in care of the **University of California, San Diego, Scripps Institution of Oceanography, 9500 Gilman Drive, La Jolla, California 92093.**

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APPENDIX B
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July 1, 1991 - June 30, 1992
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IGPP	Institute of Geophysics and Planetary Physics
IMR	Institute of Marine Resources
MBRD	Marine Biology Research Division
MLRG	Marine Life Research Group
MPL	Marine Physical Laboratory
MRD	Marine Research Division
NU	Neurobiology Unit
PORD	Physical Oceanography Research Division
PRL	Physiological Research Laboratory
SC	Scientific Collections
SG	Sea Grant Program
SOMTS	Ship Operations and Marine Technical Support
STS	Shipboard Technical Support

APPENDIX C

Awards & Honors

Tim P. Barnett
received a Special Creativity Award from the National Science Foundation.

Wolfgang H. Berger
received the Prince Albert Medal from Monaco's Institute of Oceanography.

Charles S. Cox
awarded the Maurice Ewing Medal from the United States Navy and the American Geophysical Union.

Harmon Craig
received an honorary D.Sc. degree at the 100th Anniversary Convocation of the University of Chicago.

Frederick H. Fisher
awarded the Oceanic Engineering Society's Distinguished Service Award.

Robert L. Fisher
was elected a fellow of the American Geophysical Union.

Edward A. Frieman
named chairman of a joint NASA and White House National Space Council committee to review NASA's proposal for the Earth Orbiting System.

Holger W. Jannasch
of Woods Hole Oceanographic Institution received the second Robert L. and Bettie P. Cody Award in Ocean Sciences.

Walter H. Munk
was selected 1992 UCSD Alumnus of the Year.

Joseph L. Reid
received the Alexander Agassiz Gold Medal from the National Academy of Sciences. Honored by 'festschrift' issue of Deep-Sea Research.

James R. Stewart
received the U.S. Department of the Interior Conservation Service Award. Honored as Diving Officer Emeritus by UC President David Gardner.

Bradley T. Werner
received an Office of Naval Research Young Investigator award.

Cody Award

Dr. A. Aristides Yayanos, Dr. Edward A. Frieman, Dr. Holger W. Jannasch, and Robert L. Cody after presentation of the Cody Award.

The second Robert L. and Bettie P. Cody Award in Ocean Sciences was presented by Scripps to Dr. Holger W. Jannasch, Woods Hole Oceanographic Institution, Massachusetts. Dr. Jannasch is a world leader in studies of microbial ecology and has made major contributions to understanding the role of bacteria in marine and freshwater environments.

The biennial Cody Award, first presented in 1989, comprises a gold medal, a certificate, and a ten-thousand-dollar prize presented by Scripps. Cody Awards honor outstanding scientific achievement in oceanography, marine biology, and the earth sciences.

The award was established by Mr. and Mrs. Robert L. Cody. Robert Cody's great aunt, Mary Bennett Ritter, was the wife of Scripps's first director William E. Ritter.

APPENDIX D

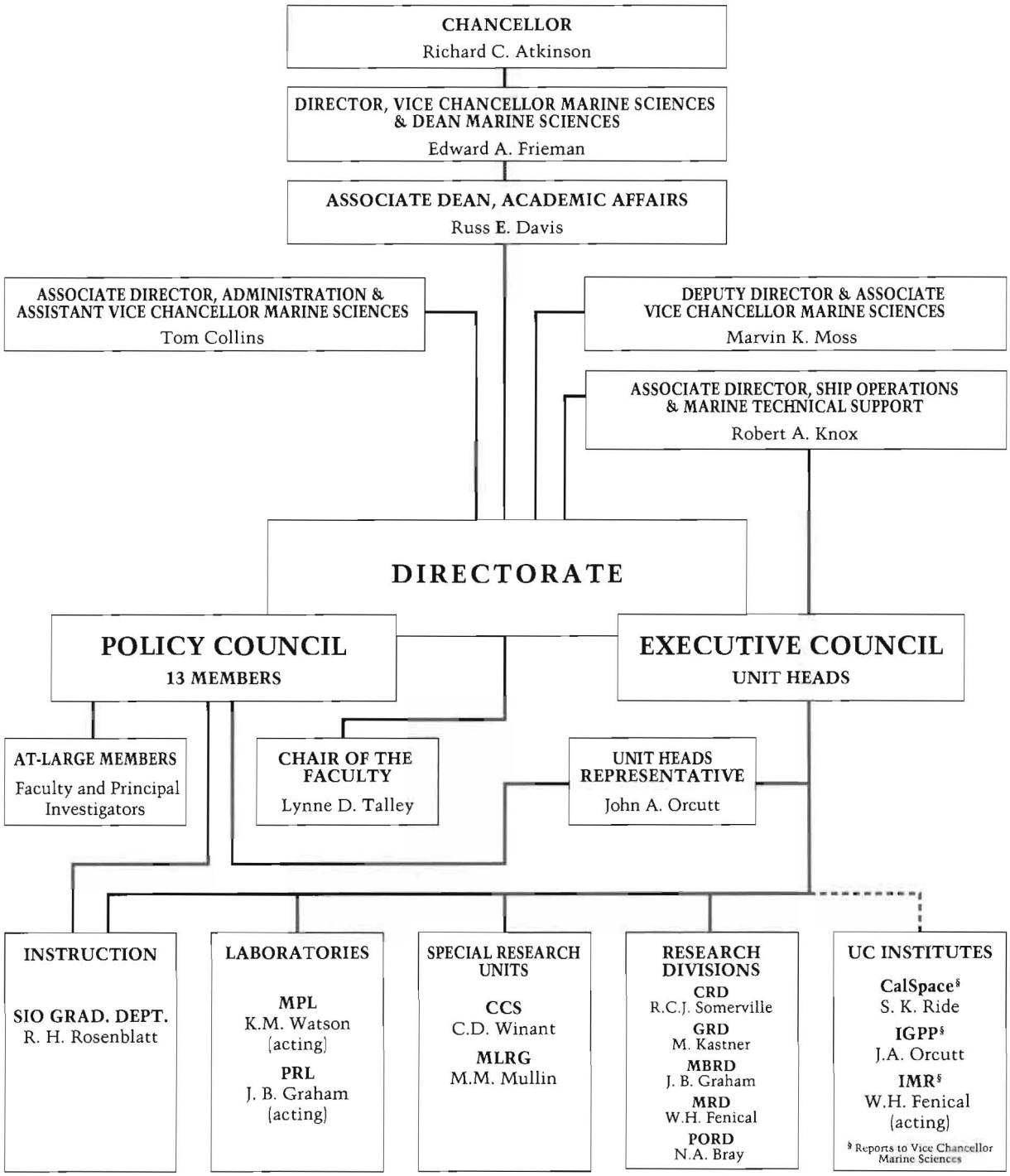
Current Funds

Agency	Expenditures*	Percent of Total
Federal Government		
National Science Foundation	20,422,832	26.83
Navy, Department of the	10,948,790	14.39
Commerce, Department of	3,204,740	4.21
Army, Department of the	2,460,330	3.23
National Aeronautics and Space Administration	3,076,173	4.04
Air Force, Department of the	466,274	0.61
Health and Human Services, Department of	1,240,909	1.63
Interior, Department of the	1,533,281	2.02
Energy, Department of	1,444,130	1.90
Other	447,866	0.59
Total Federal Government	**$45,245,325**	**59.45**
State General Funds	16,214,863	22.31
Private Gifts and Grants	11,195,496	14.71
Overhead Funds	1,639,893	2.15
State of California	1,242,177	1.63
Endowment Funds	477,586	0.63
Local Government	54,996	0.07
Sales and Services	(874,768)	-1.15
Reserves	912,923	1.20
Total Current Funds Expenditures	**$76,108,491**	**100.00**

*Includes overhead

APPENDIX E

Organization*



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CCS	Center for Coastal Studies
CRD	Climate Research Division
GRD	Geological Research Division
IGPP	Institute of Geophysics and Planetary Physics
IMR	Institute of Marine Resources
MBRD	Marine Biology Research Division
MLRG	Marine Life Research Group
MPL	Marine Physical Laboratory
MRD	Marine Research Division
PORD	Physical Oceanography Research Division
PRL	Physiological Research Laboratory

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***Wayne Burt**. August 1991. Dr. Burt was a Scripps graduate student. He received his Ph.D. in 1952.*

***Paul Charles Fleischer**. April 1992. Paul Fleischer was a machinist at the Physiological Research Laboratory from 1950-1969. He designed and fabricated numerous devices, and participated in the first Amazon expedition aboard R/V* Alpha Helix.

***Jery Graham**. August 1991. Jery Graham was senior electronics technician in MLRG from 1966-1981 where he maintained and deployed deep-free vehicles, deep-sea 'monster cameras', and early versions of the TDS (now CTD) instrument.*

***George L. Matson**. January 1992. George Matson was a former assistant director of administration and finance for Scripps. He began his UCSD career in 1965, and worked at Scripps from 1974–1983.*

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***John Edwards Tyler**. June 1992. John Tyler came to Scripps in 1952 as a senior member of the Visibility Laboratory where he served as assistant director during its early years. He pioneered work in the experimental methodology, instrumentation, spectral distribution of light in the ocean, and theory of ocean optics. Tyler retired in 1973.*

***Leo Weuve**. May 1992. Leo Weuve was site director of the Cecil and Ida Green Piñon Flat Observatory. Through 21 years of (mostly volunteer) work, Weuve assisted researchers in operating a wide range of prototype geophysical sensors.*

***Bernard D. Zetler**. September 1991. Bernard Zetler was a research oceanographer in IGPP from 1972-1985. He was an expert on tides, nearshore currents, and tsunami waves.*

All correspondence pertaining to this specific report should be directed to
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