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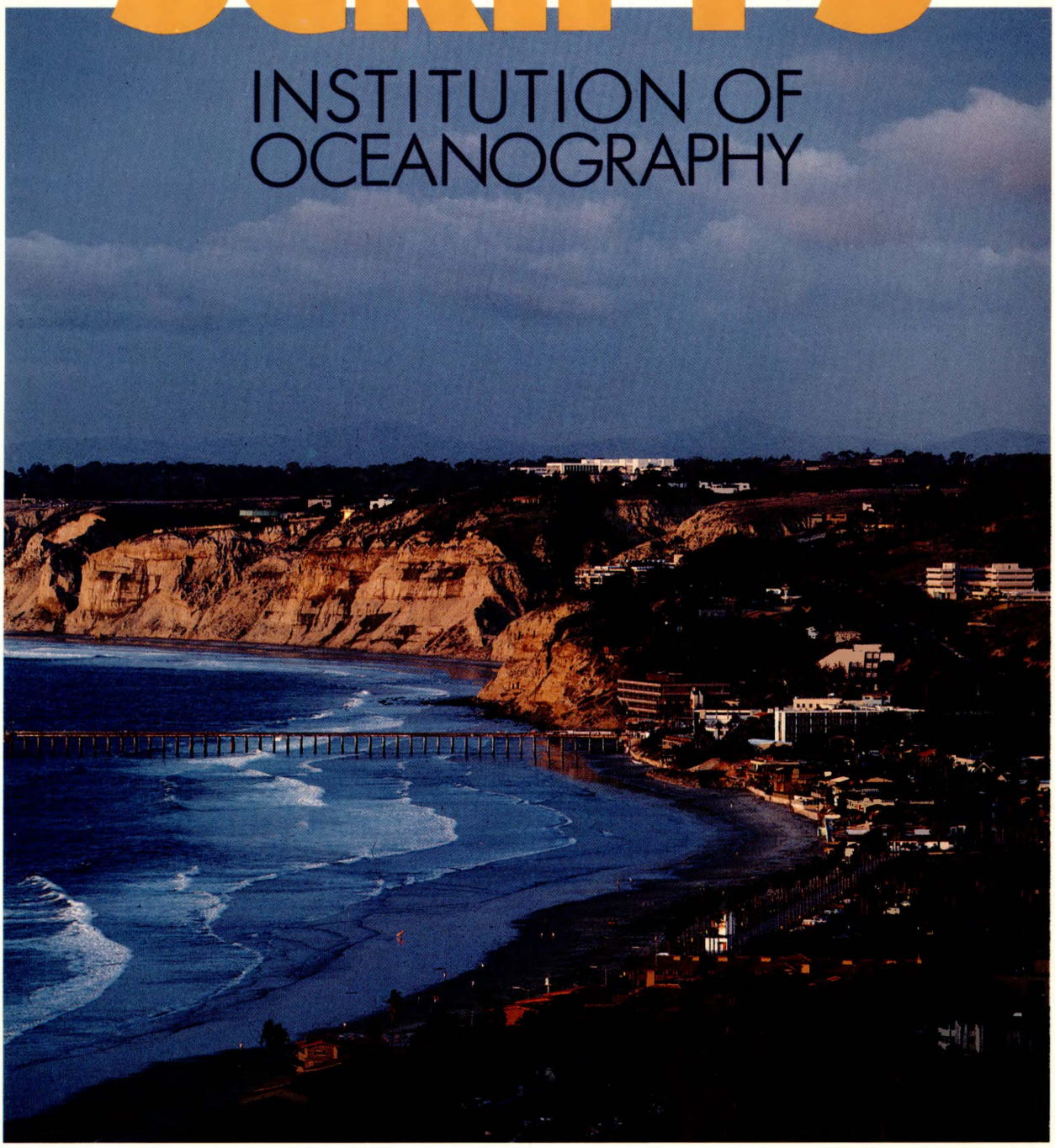

Annual Report 1984

University of California, San Diego

DEDICATION

Dr. Seibert Q. Duntley brought the Visibility Laboratory to Scripps from the Massachusetts Institute of Technology in 1952. Dr. Duntley served as director of the laboratory, professor of oceanography, and a research physicist until 1977, when he became professor emeritus. Dr. Duntley has designed optical instruments, and studied remote sensing, all aspects of visibility, and optical properties of diffusing materials. The Optical Society of America awarded him the Frederic Ives Medal in 1961. He has served on the governing board of the American Institute of Physics, been on the editorial board of various journals, and has written more than 125 publications.

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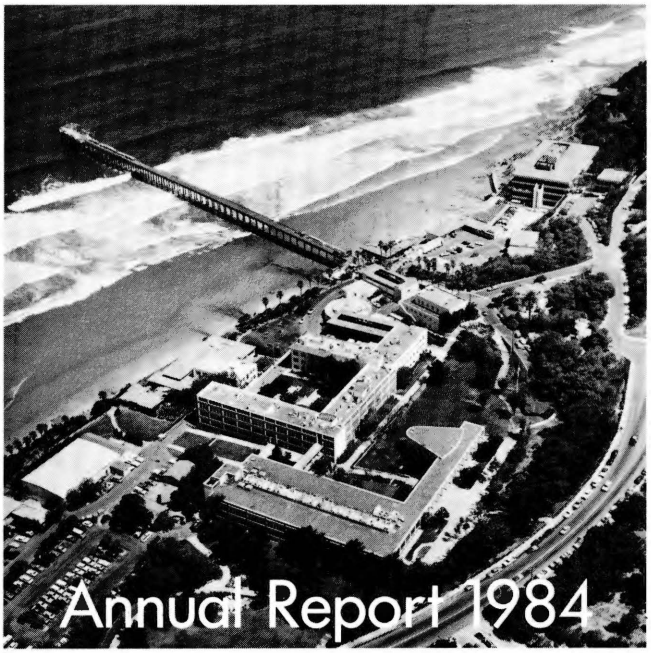

University of California, San Diego

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University of California, San Diego, Volume 18, Number 1, January 1985. ■ A series of administrative publications of the University of California, San Diego, La Jolla, California 92093. Second-class postage paid at La Jolla, California. ■ A major portion of the work reported herein was supported by the National Science Foundation and the Office of Naval Research. ■ Four issues a year: January, March, May, and July. USPS 646-820 ISSN 0194-2816.

INTRODUCTION

The most exciting event at an oceanographic institution is the acquisition of a new vessel. This year it was R/V *Robert Gordon Sproul*—a larger replacement for R/V *Ellen B. Scripps*. So far the vessel's performance has exceeded expectations. It was a great pleasure for me to name the ship for one of the greatest university presidents this country has known. After his retirement, President Sproul was my neighbor on Tamalpais Road in Berkeley.

We had more celebrations this year than usual. There was a celebration of the eightieth anniversary of the founding of the institution, including an open house that drew 4,000 visitors. We had an elaborate cornerstone laying for the new Physical Oceanography and Space Science Building, including a time capsule affair. There also was the dedication of Old Scripps Building as a National Historic Landmark—a credit to the devoted group that worked hard to bring it about.

We had two campuswide celebrations with symposia—one for Roger Revelle's seventy-fifth birthday, and one for my sixty-fifth.

There were many honors and awards to members of SIO. Among the more notable were Docteur Honoris Causa to both Harmon Craig and Miriam Kastner. Roger Revelle received the National Science Board's fifth Vannevar Bush Award of Statesman of Science, and he shared the 1984 Tyler Ecology-Energy Prize with Edward O. Wilson.

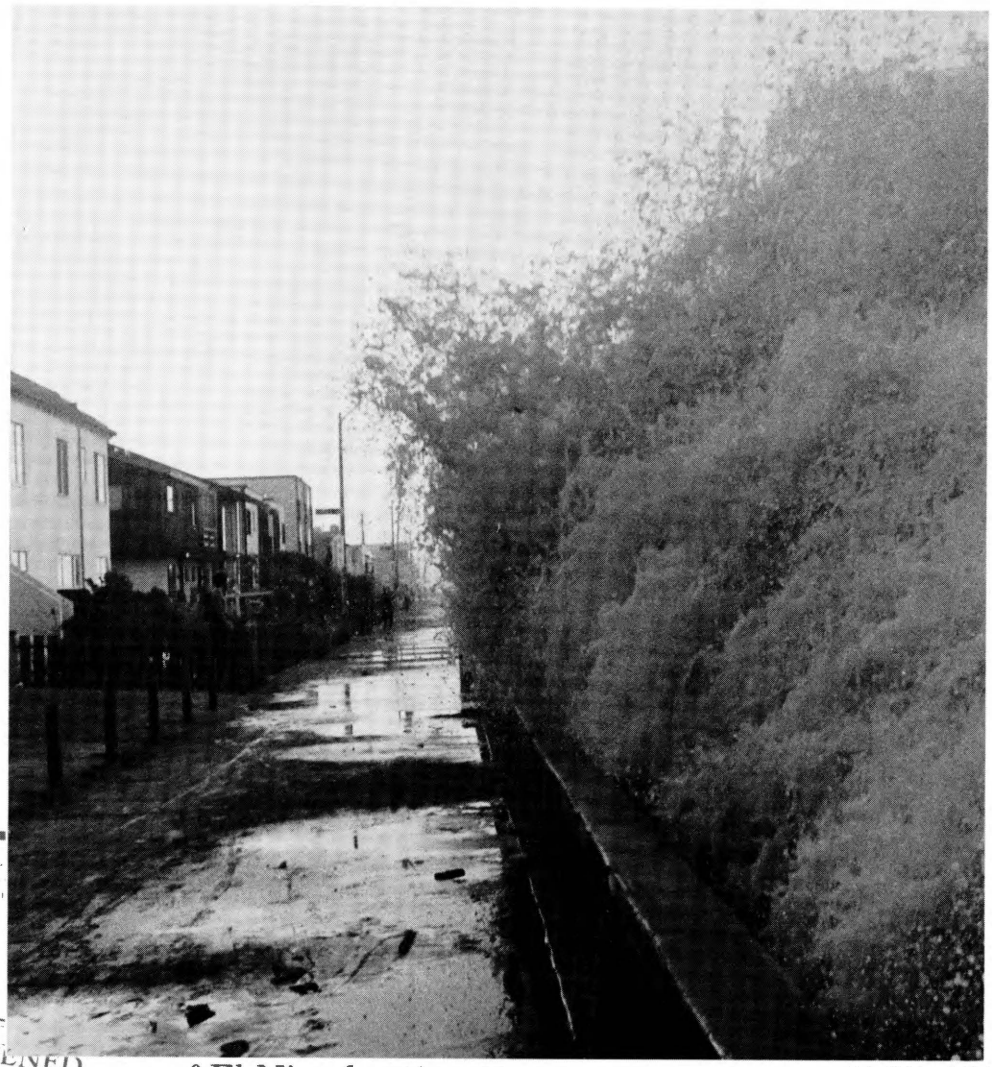
With the upsurge in the governor's budget we look forward to a period of expansion. This last year, approval was obtained for financing a replacement for the pier (the time was running out!); planning is now fully under way.

We can now realistically look forward to a Collections Building in a few years; this would complete our long-term program, and thought must now be given to formulating a new one.

William A. Nierenberg

William A. Nierenberg, Director
Scripps Institution of Oceanography

HIGHLIGHTS



Union-Tribune Publishing Co.

Warm Water Perils State Anchovy Fleet

(Continued from B-1)

Temperature readings taken off the Scripps Pier in La Jolla are 3.1 degrees Fahrenheit higher than nor-

In the News

Blasts from El Niño

California took a beating from the weather this winter, but it was not alone. Meteorologists say that the California storms are part of a vast system of oceanic and atmospheric events that affected weather round the world.

Pacific nore tributing to and drought

Reporter

WHATEVER HAPPENED TO SUNNY CALIFORNIA?

An earthquake, a tornado ... downpour—is it ...

Scripps Scientists Cautious

Warmer Sea May Pose Threat to Fish

By KEAY DAVIDSON, *Times Staff Writer*

LA JOLLA—Rising tempera- ... much of the Pacific ... but there were few scientists eager to make detailed predictions Wednesday. ... temperatures from

The warming is called Nino," or "The Child," a r to Christmas because suc warming tends to occur du winter.

Forgive Us, El Nino

Los Angeles Times

Sunday, November 27, 1983

The meteorological phenomenon known as El Nino has had serious and disruptive effects on the world's climate, but we think that it is tempting fate to blame it for *all* of the unseasonable weather—and all of the unreasonable antics of sea creatures—along the California coast.

Let someone mention that ...

reach this point in their southern migrati the Bering Sea until around Christmas time.

Why are the giant mammals a full schedule in trekking south to t grounds in the coves of Baja Califo

El Nino comes of age — and causes problems

...on of El Nino heating ...nings up off our coast

...ndling parent, McGowan said. ...e said he can't even guess what ...ct the phenomenon, seen only ...before, might have on the West

FLOOD, TYPHOON, TORNADO— AND DROUGHT

Complex currents, winds, and pressure pockets caused the 1983 plague of contradictory weathe

Powerful rhythm of the sea

By Jerome Wanetick

Special to The Tribune

AS THE high waves of this past winter's storms swept the beaches of Southern California, residents of the coastal communities bemoaned the rising ire of

California Coast Heats Up

Scientists Attend Informal Weather Workshop at Scripps

By CLYDENE NEE

Staff Writer

encourage interdisciplinary substitute

nference at Scripps

Scientists Sound Alarm on Ocean Warming Trend

By LANIE JONES, *Times Staff Writer*

LA JOLLA—"A major climatic anomaly of the ocean-atmosphere system" has warmed the waters of the Pacific Oce ing patterns ar

the workshop and its report did offer significant new details on how "El Nino" has affected equatorial regions of the Pacific as well as

Havoc on Land, Sea

El Nino: the World Turns Topsy-Turvy

Los Angeles Ti

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Continued from F1

populations "catast —Warm, moist wetter than norm

Weather Watch

Scientists Study the Cli

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Sea warming

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Expert Say

An unus the coast north for level to r and thre

By CHERYL

Staff Writer, The San D

Douglas Inman dire Institution's Center for

Warm Water Jeopardiz

By WARREN FROELICH

is chasing anchovies out to sea is lur-

gist at the

***EL NINO:* Global Cli**

El Niño

Is there a relationship between bubonic plague in New Mexico and fires in Australia? Between rattlesnake bites in Montana and the reversal of the Pacific Trade Winds? Between the disappearance of 17 million birds from Christmas Island and the slowing of the earth's rotation? Between floods in Ecuador and mudslides in southern California?

No one knows for sure, but all of the above phenomena have been suggested as direct or indirect consequences of the 1982-1983 El Niño event.

What is El Niño? To a Peruvian fisherman it is the disappearance of the anchoveta and the disruption of a multimillion dollar fishing industry. To an oceanographer, it is the anomalous warming of sea-surface temperature in the eastern equatorial Pacific. To a meteorologist, it is a major perturbation of the global atmospheric and circulation fields.

The nature of the interactions and feedback mechanisms between ocean and atmosphere, and their ecological, sociological, and economic ramifications have been studied for the past two decades. Some of the major connecting links were blatantly illustrated during the 1982-1983 El Niño, but the mechanisms that initiate this complex phenomenon remain a mystery.

The 1982-1983 El Niño broke records in terms of intensity and extent, and demolished some favorite hypotheses. It began in the wrong place, at the wrong time. In retrospect, signs of development were apparent in June 1982. At the time, however, these early data were generally dismissed as faulty satellite interpretation. So bizarre were the characteristics of the 1982-1983 event that some scientists believe it was not a true El Niño and deserves its own name.

Climate

During the summer and fall of 1982, Scripps scientists concerned with the Pacific tropics noted an increasing number of oceanic and atmospheric anomalies and found themselves surrounded by controversy over the causes. Sea-surface temperatures in the central equatorial Pacific were too warm, and unusually large amounts of rain fell there. The wind index for the southeast trades fell below any previously recorded value. As months went by, the evidence became clearer and the anomalies more widespread; something of unusual magnitude was definitely going on.

Feeling that this gigantic puzzle would be unraveled only with information from many sources, three Scripps scientists organized an El Niño workshop, sponsored jointly by the California Space Institute (Cal Space) and Scripps. The sponsors hoped to acquaint the scientific community with the diversity of ongoing studies, to define the data resources available, and to encourage interdisciplinary collaboration. The one-day meeting was attended by more than a hundred scientists, representing universities, private industries, and federal, state, and local governments. As numerous investigators presented their observations, there emerged a preliminary description of the sequence of physical and biological events that had occurred in the ocean and atmosphere since mid-1982. Participants agreed that this El Niño event appeared to be one of the largest in the past century.

One of the earliest indications of the onset of El Niño—an anomalous decrease in the intensity of the trade winds—emanated from routine processing of merchant ship observations of surface winds by the Climate Research Group (CRG). The warming of equatorial waters during El Niño usually takes place over a period of several months and persists for a year or more before waning. Concurrent with the oceanic warming, the tropical atmosphere undergoes widespread changes that indirectly affect midlatitude

weather patterns. The use of the slow evolution of El Niño as a means to predict climatic anomalies several months in advance has been a CRG goal.

Previous research has indicated that the relationship between El Niño and weather is complex and differs from episode to episode. One of the experimental seasonal forecasts for winter 1982-1983 depended on El Niño associated conditions during fall 1982. Abnormally heavy precipitation in California was accurately forecast, even though the previous El Niño was associated with drought.

Recently, a possible precursor for El Niño has been identified. This is a propagating "wave" in the sea level pressure field that first appears over the Asian continent and involves interactions between the Indonesian convergence system and a region of high pressure over Siberia. In retrospect, the timing and magnitude of the 1982-1983 El Niño were highly predictable.

The 1982-1983 El Niño dramatically demonstrated the interactions between ocean and atmosphere. However, many questions remain before El Niño events can significantly improve weather prediction. An international program—Tropical Ocean Global Atmosphere—is being organized to monitor the next El Niño episode and to help answer some of these questions.

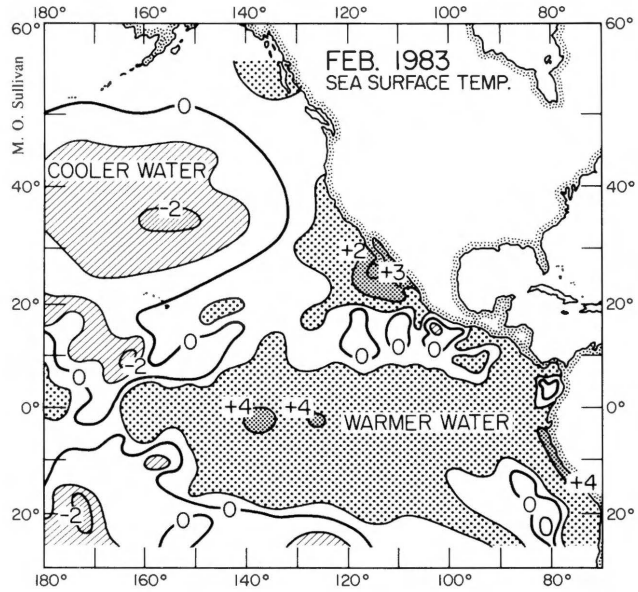
California Current

El Niño events occur irregularly in the equatorial Pacific every five to eight years. It is unusual, however, for the magnitude to be great enough to cause a major perturbation in the ocean off California. But this did happen in 1982-1983, and it influenced the research of numerous scientists whose work is not usually associated with El Niño phenomena. By the end of 1982, the effects of El Niño were recognized as far north as southern California. (These effects later extended to the Gulf of Alaska.) Sea level was 23 cm above normal, indicating a weakening of the south flowing California Current; sea-surface temperature off Scripps pier was 3°F above normal, and swarms of tropical pelagic red crabs were appearing on local beaches.

For 30 years scientists from the Marine Life Research Group, together with counterparts from the National Marine Fisheries Service and California Department of Fish and Game, have monitored the physics, chemistry, and biology of the California Current (California Oceanic Fisheries Investigations—CalCOFI). The resulting data are unequaled for any other marine ecosystem and provide a detailed picture of the long-term average conditions in the California Current, against which scientists can evaluate low-frequency perturbations such as El Niño.

When the first signs of a warm water event in the California Current became apparent in late 1982, everyone agreed it must be monitored. Unfortunately, the next scheduled CalCOFI survey was not until January 1984. Because scientific funds and ship time are tightly allocated a year or more in advance, spur-of-the-moment programs such as this are not easily accommodated. Nevertheless, scientists, funding agencies, and ship schedulers banded together with money and ship time on Scripps vessels supplemented by NOAA and Oregon State University vessels. In the end, monthly sampling during 1983 was achieved. This would fill in the data gap until the start of the scheduled 1984 CalCOFI survey. Much of the work for these "mini-CalCOFI's" was done by volunteers: marine technicians recruited from retirement, academic personnel, and graduate and undergraduate students from Scripps, San Diego State University, U.C. Santa Barbara, and Rice University, and one newspaper reporter. In spite of limited time and personnel and bad weather, 12 transects were run across the core of the California Current, 112 stations were occupied, and an invaluable set of data was amassed, describing the growth of the largest perturbation of a marine ecosystem ever recorded.

While most El Niño indicators have been near-surface measurements, the CalCOFI data extend down to 500 m. While satellite imagery suggests that the greatest anomaly of surface temperature occurred near the coast; the deeper oceanographic measurements show that greater anomalies occurred at depths between 50 m and 80 m, and more than 100 km offshore. This appeared to result from a deepening of the summer mixed layer and an increase in the eastward transport of warm, nutrient poor water from the Central Pacific. The biological component of the ecosystem responded dramatically. The quantity of zooplankton observed during 1983 was consistently lower than observed at any time during the 30-year study. It may be decades before all of the information has been processed.



SEA-SURFACE TEMPERATURE ANOMALY MAP for February 1983, the most representative month of El Niño. Warmest water shown here is 4°C above normal.

Wave Studies

The Ocean Engineering Research Group (OERG) studies the wave climate of the Eastern Pacific. During the winter of 1982-1983, two phenomena clearly emerged: the OERG was measuring waves of greater height and longer period than they had ever recorded previously, and many wave-measuring instruments were being destroyed during the storms because of unusually severe shoreline erosion. A swell train with a period of 18 seconds is considered extreme, but during the winter of 1982-1983 there were many storms with periods longer than 20 seconds, and one that reached 25 seconds! Both the intensity of the storm waves and their impact on the shoreline resulted from their anomalous direction of approach—directly from the west. The very long fetch obtained from a huge, nearly stationary low in the mid-Pacific produced long, high waves that hit beaches usually protected from typical northwestern winter storms.

There were eight major storms observed from mid-January to mid-March 1983. One possible explanation was the atmospheric conditions attributable to the strong El Niño formed several months earlier. To clarify this relationship, scientists reconstructed storm wave activity during past El Niño events from historical weather data. Fourteen El Niño events have been identified since 1900. During the same 84-year period, there were 18 storms off southern California with wave heights of 6 m or greater. Nine of these occurred in the winter following the start of an El Niño. If the storms were randomly distributed in time, only three such events would have occurred during El Niño years. In southern California, there were four storms with periods of 20 seconds or longer—all of them following El Niño events. Wave activities during all El Niño storms exceeded those during non-El Niño periods. A strong association between El Niño conditions and large and destructive storms in southern California was clearly established.

Kelp

Ecologists with the Ocean Research Division (ORD) have spent a decade studying California kelp forests—complex communities of algae and animals—many of which are important to sport and commercial fisheries. Previous research had shown small-scale disturbances by ''normal'' winter storms to be important to community structure because they removed a few older, larger plants, facilitating recruitment of young plants. The number of massive storms between November 1982 and April 1983 caused unprecedented destruction of kelp forests.

Alerted to the magnitude of the developing El Niño by the Scripps/Cal Space workshop, and aware of the potential for winter storm damage to kelp beds, ecologists realized that El Niño conditions could change the structure of kelp forest communities for years to come.

The necessary funding was found to determine the nature and extent of the storm mortality and to census surviving populations; this baseline data is essential to accurate evaluation of the subsequent recovery.

Oceanographers now realize that the physical forcing functions of the 1957-1959 and 1982-1983 El Niño events and the resulting environmental conditions were very different. Human impacts on the nearshore zone have changed considerably in the intervening years; better water quality and a large sea urchin fishery may have stabilized the kelp bed community, making recovery more rapid than it was in the 1960s, but is still likely to take several years.

Catastrophic disturbances such as massive forest fires, volcanic eruptions, hurricanes, or El Niño events are very much a part of nature. They overwhelm the normal mosaic of successional stages in a community, and the effects may dominate community structure for decades. Understanding these rare events is a major challenge for biologists.

Climate research, oceanography, ocean engineering, and kelp bed ecology are only a few of the diverse scientific disciplines involved in the study of the 1982-1983 El Niño. The study yielded the most comprehensive description yet of the development and relaxation of El Niño, because of the unprecedented magnitude and extent of the event and the early warning of El Niño provided by modern science. Do we know why El Niño started or why it ended? No, but some of the links between the ocean and atmosphere are clearer. New hypotheses have been formed, old ones tested and modified, and a few discarded. Perhaps the solution to mysteries surrounding El Niño will arrive with the next one.

Suggested Reading

Canby, Thomas Y. El Niño's ill wind. *National Geographic*, v.165, no. 2, 1984. pp.144-183.

Oceanus, v.27, no. 2, 1984.

Science, v.222, no. 4629, 1983. pp. 1189-1210.

Ocean Acoustic Tomography

Physicians use X-rays to produce CAT scans—detailed pictures of the interior of the human body—and seismologists use seismic waves to determine the earth's interior structure. Now oceanographers are using sound waves to study ocean circulation. Dr. Carl Wunsch, of the Massachusetts Institute of Technology, and Dr. Walter H. Munk have named their new technique *ocean acoustic tomography* in analogy with the medical procedure known as CAT—computed axial tomography.

Observing ocean circulation is difficult. The oceans' density and velocity fields fluctuate on spatial scales from millimeters (microstructure) to thousands of kilometers (the basin scale) and on time scales from seconds to millions of years. Traditional tools for monitoring the large-scale ocean circulation include instruments moored to the seafloor or instruments lowered from ships. These tools are inadequate for measuring ocean fluctuations that have spatial scales greater than 100 km and time scales of weeks. Because of energetic, random eddy motions throughout the ocean interior (the oceanic mesoscale, analogous to atmospheric storms), accurate ocean mapping requires observations spaced about one eddy scale apart, i.e., 50 km. The cost of such arrays is prohibitive. The ocean changes on time scales of weeks; the areas measured by instruments lowered from slowly moving ships change while they are being observed—therefore the ocean cannot be accurately mapped.

Several new approaches to the problem of observing large-scale ocean fluctuations are currently under study, including the use of satellite measurements and freely drifting buoys (both surface and subsurface) whose motions are tracked for long periods. Walter Munk, Peter Worcester, and Robert Knox lead a Scripps group that is using acoustic techniques to measure large-scale temperature and velocity fields.

The ocean is almost transparent to sound, and the speed with which sound travels is a function of temperature and velocity. Transmission of sound over long distances is possible in the ocean (in contrast to electromagnetic radiation, which is rapidly absorbed). Fluctuations in the travel time of the sound relate to oceanographic parameters through the use of inverse theory. Over much of the ocean there is a minimum in sound speed at a depth of one km (the SOFAR channel). The waveguide that results gives rise to a variety of ray paths, which connects acoustic sources and receivers moored near the sound channel axis. Each ray samples the water column with different weighting in the vertical, so that the depth dependence of temperature and current fluctuations can be determined by sources and receivers moored at a single depth. This technique we call ocean acoustic tomography.

The first ocean acoustic tomography experiment was conducted in 1981, to construct three-dimensional maps of mesoscale variability in the ocean. A consortium consisting of groups at Scripps, three other U.S. universities, and NOAA deployed four acoustic sources and five acoustic receivers to map a 300-km-by-300-km square in the Northwest Atlantic. Maps of sound-speed anomaly (which is closely related to temperature and density anomalies) were constructed from the measured travel times and compared with maps obtained from conventional shipboard CTDs.

The comparisons reveal similar patterns, but do not agree in detail. The acoustic travel times were not measured as accurately as hoped because of instrumental limitations, and the maps constructed from the acoustic data therefore have relatively large error bars (approximately $\pm$ 2 m/s, or $\pm$ 0.4°C). Also, acoustic travel times could be used to construct maps once a day (sound travels at about 1500 m/s, or 3000 kts, in the ocean), whereas the ship (moving at about 10 kts) required approximately three weeks to complete a single CTD survey. Thus the ocean changed while the survey was being conducted. The inverse results were consistent with the measured acoustic travel times to within the expected error levels, however, indicating that the basic procedure was functioning properly.

The 1981 experiment is an example of *density* tomography, in which separate sources and receivers are used to obtain one-way travel times that then can be converted directly to sound-speed anomaly and then to density anomaly. Our next experiment, conducted in 1983 in conjunction with Woods Hole Oceanographic Institution, tested mesoscale *velocity* tomography. Two source/receiver pairs were moored 300 km apart, and sound pulses were simultaneously transmitted in opposite directions. Sound that travels with a current travels faster than sound traveling against a current, so that the differences in travel times of the various rays can be converted, using inverse theory, to the vertical structure of the current components along the line connecting the transceivers. Project scientists are analyzing the data from this experiment, and preliminary results are encouraging. Velocity tomography may make it possible to measure the relative vorticity of the ocean averaged over large areas.

Relative vorticity is essentially the local rate of rotation of the ocean relative to the earth, and is a quantity of fundamental importance in the dynamics of the ocean. We know of no other technique that has the potential to make this measurement.

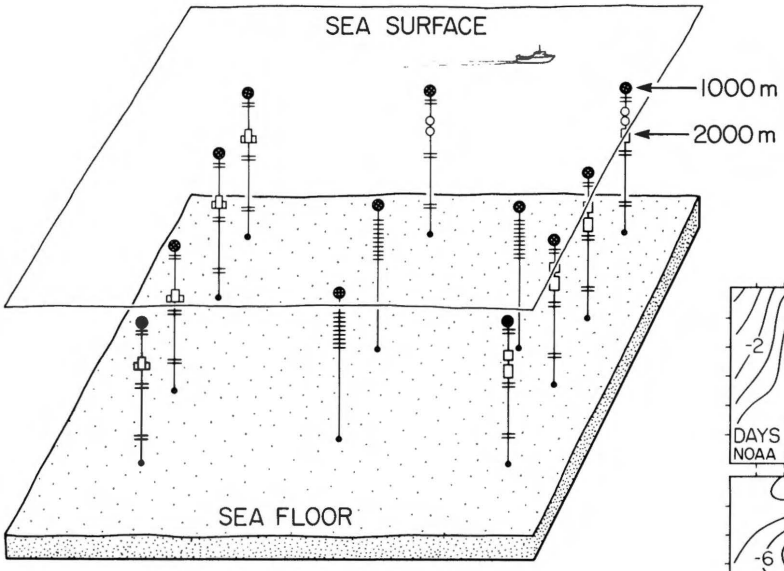
Acoustic measurements inherently provide integral properties of the ocean, because the travel time depends upon the sound-speed field along the ray between source and receiver. We are now preparing gyre-scale experiments designed to exploit this property by measuring characteristics such as heat content between sources and receivers separated by 1000 km. The 1981 experiment measured integral properties that were then effectively differentiated using inverse theory to produce maps of the ocean sound-speed field; we are now designing experiments that focus on the integral properties themselves.

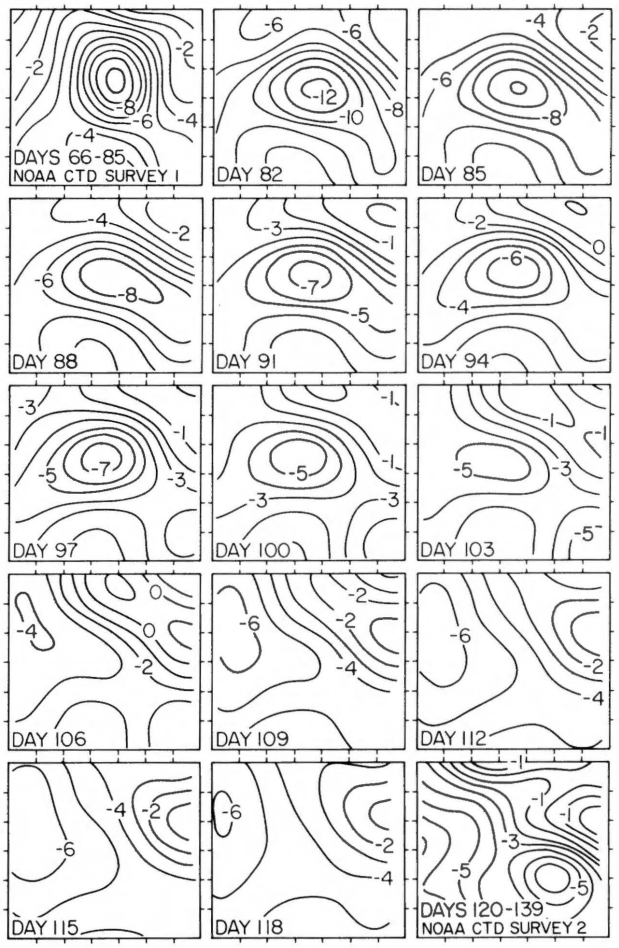
Suggested Reading

Munk, Walter and Carl Wunsch. Ocean acoustic tomography: a scheme for large scale monitoring. *Deep-Sea Research*, v.26, 1979. pp.123-161.

Munk, Walter and Carl Wunsch. Observing the ocean in the 1990's. *Philosophical Transactions of the Royal Society of London, A*, v.307, 1982. pp.439-461.

Ocean Tomography Group. A demonstration of ocean acoustic tomography. *Nature*, v.299, 1982. pp.121-125.

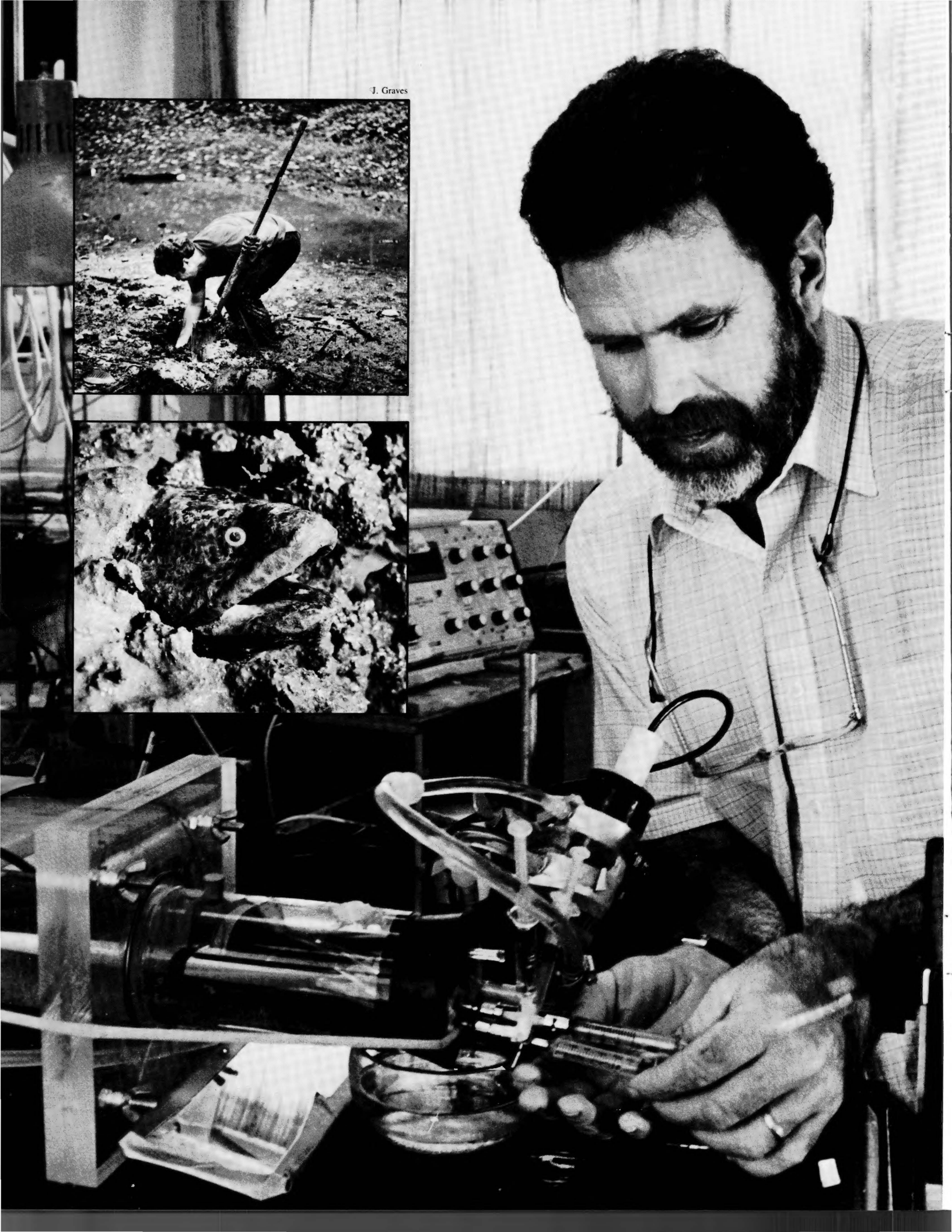




Above, **GEOMETRY OF THE 1981 OCEAN ACOUSTIC TOMOGRAPHY EXPERIMENT. Four acoustic source moorings were installed on the west (left) boundary of the 300-km-by-300-km experimental area. Five acoustic receiver moorings were installed on the north (top) and east (right) boundaries of the area. All acoustic instruments were at approximately 2000-m depth, and all sources transmitted to all receivers. Three moorings with conventional current meters and temperature-pressure recorders between 200-m and 1300-m depths were deployed in the interior of the experimental area to provide comparisons to the acoustic results. All acoustic moorings used subsurface floats at 1000-m depth to eliminate wave forces and reduce horizontal excursions of the instruments. The experimental area is over the Hatteras abyssal plain with depths varying between 5300 and 5600 m.**

Right, **TIME SERIES OF TOMOGRAPHIC MAPS from the 1981 ocean acoustic tomography experiment at 700-m depth, with maps generated from conventional conductivity-temperature-depth (CTD) surveys at the beginning and end. Each square is a plan view of the 300-km-by-300-km experimental area, with contours of constant sound speed drawn at 1 m/s intervals (corresponding roughly to 0.2°C temperature intervals). The sequence of maps shows a central cold (low sound speed) eddy present at the beginning of the experiment that remains quite stable until yearday 100, after which it rapidly begins to move west. Acoustic tomography is uniquely well suited to measure such behavior.**

J. Graves



RESEARCH ACTIVITIES

Many of the scientific projects being conducted at Scripps are reviewed briefly in these reports. Some departments have elaborated on a few studies, while other groups give a summary of many projects. The majority of these studies are being funded by the National Science Foundation, Office of Naval Research, Department of Energy, Department of Commerce, and other governmental agencies. Scientific papers listed in the Publications section will lead the reader to a more in-depth coverage of the topics discussed in the Research Activities section.

Physiological Research Laboratory

Scientists in the Physiological Research Laboratory (PRL) concentrate on physiological and biochemical adaptations of aquatic and terrestrial animals. Dr. A. Aristides Yayanos continues studies of deep-sea barophilic bacteria. It is likely that pressure adaptation is a hallmark of deep-sea bacteria, which means that non-pressure-adapted bacteria from the deep sea are either there as a consequence of ocean mixing processes or appear to be there as a sampling artifact.

Growth physiology studies of these bacteria show that deep-sea hydrostatic pressure may govern the distribution and evolution of oceanic life. It is possible that pressure adaptation in deep, stable, warm seas (such as the Sulu and Mediterranean seas) may be different from that in deep, cold seas. There also may be deep-sea microenvironments where bacterial metabolism causes elevated temperatures (for example, in the intestine of a fatty animal).

Deep-sea bacteria are presently the only type of barophilic organism in laboratory culture. Therefore, they are important tools for discovering the molecular basis of barophily and for investigating the effects of contaminants in the marine environment.

Dr. Edvard A. Hemmingsen and a graduate student studied bubble formation by decompression in various organisms, focusing on factors that cause bubble formation even with small degrees of gas supersaturations. Results of this investigation cast doubt on the view that organisms contain reservoirs of microscopic gas nuclei. A number of other mechanisms for initiating bubbles appear to be operative: in crustaceans and fish, for example, bubbles can nucleate

DR. JEFFREY B. GRAHAM withdraws a water sample through an indwelling branchial catheter from the bimodally breathing swamp eel *Synbranchus* to estimate the oxygen extraction efficiency of water ventilation. *Upper left,* Dr. Graham digs for *Synbranchus* in Ocelot Pond, Panama. *Lower left,* swamp eel emerges from its burrow.

spontaneously at contact points between sliding surfaces. In the absence of any motion, very high gas supersaturations can be tolerated.

Studies of the pericardioperitoneal canal function in sharks and rays continue in Dr. Jeffrey B. Graham's laboratory. Decompression of the pericardium via the canal can occur during swallowing, vigorous swimming, and probably in response to increased venous blood flow to the heart. Dr. Graham also participated in a tracking study of the sea snake *Pelamis platurus* along the Pacific coast of Panama. This snake spends up to 90 percent of its time diving below the water surface, as deep as 25 m, where it can remain for up to two hours. Dr. Graham and a colleague are studying the cardiorespiratory reflexes of the bimodally breathing swamp eel *Synbranchus*.

Dr. Harold T. Hammel and James E. Maggert are exploring the central nervous mechanisms that control nasal salt gland excretion in marine birds. Their question is: How does the nervous system recognize sodium chloride excess in body fluids and actuate salt gland excretion to correct the imbalance? No single factor, be it NaCl concentration, extracellular fluid volume, or toxicity of extracellular fluid can account for the driving signal to the salt gland. A number of neuroendocrine agents have been excluded. The phenomenon is an example of proportional control combined with integral or offset control; however, the nature of the effective stimulus remains obscure.

Temperature regulation by homeotherms was studied by Dr. Martha E. Heath. She investigated the contribution of thermoreceptors located in the skin, core, and central nervous tissues, as well as their mode of integration. Dr. Heath carried out a study on rats that had their cutaneous face and trunk thermoreceptors eliminated. The rats were able to thermoregulate well in the absence of these receptors. This suggests (1) an enormous redundancy in the cutaneous thermoreceptor population so that the relatively small portion of thermoreceptors left in the skin of the extremities was sufficient for driving the thermoregulatory responses to cool environments; or (2) that core thermoreceptors became more actively involved in driving thermoregulatory responses.

In another investigation, Dr. Heath determined the relationship between hypothalamic temperature (thy) and rate of heat production. Cutaneous denervation of face and trunk significantly reduced the sensitivity of the heat production response to changes in thy. These findings indicate a significant impact of cutaneous denervation on input to the thermoregulatory mechanism. There may be enough overlap within the thermoregulatory mechanism that gross elimination of thermoreceptors does not significantly affect it.

Dr. Fred N. White's studies of cardiorespiratory gas exchange in diving turtles demonstrate that oxygen depletion from the lung continues at a steady rate while influx of carbon dioxide is far below metabolic production. The missing carbon dioxide is stored in tissues where its acidifying influence favors unloading of blood-borne oxygen to the tissues. The less acidic environment of the lung favors oxygen uptake from the major oxygen reserves. Thus the time available for oxidative metabolism is extended until most of the oxygen within the lungs is used.

One determinant of selective distribution of carbon dioxide is the occurrence of a right-to-left intracardiac shunt (a portion of venous blood bypasses the lungs). For the diving turtle, the condition is just one of a number of adaptations to underwater life. Right-to-left shunt also occurs during human fetal development (a pathological condition if persisting in infants). The studies on diving turtles have implications for the dynamics of gas exchange in infants with intracardiac shunts.

Dr. White continues to study the acidity control of body fluids by cold-blooded animals and the implictations of these findings for chemical management of the blood of patients subjected to hypothermia for cardiac repair. These studies have helped to provide a novel blood management rationale, used increasingly in surgeries around the world. One benefit is a decline in life-threatening cardiac electrical abnormalities associated with hypothermia.

Physiological and behavioral adaptations to swimming and diving in aquatic mammals are the focus of Dr. Gerald L. Kooyman's research. In collaboration with Dr. Randall W. Davis and others, Dr. Kooyman completed experiments on the basic hydrodynamic properties of seals, sea lions, and porpoises. All animals exhibited low levels of drag and nearly perfect hull shape compared to an ideal spindle. Energetic requirements to overcome flow resistance were measured in these three mammals, and energy output for the distance traveled was found to be lower than for any other vertebrates except fish. The energy source for powering the swimming activity of seals was studied with radioisotopes. Preliminary results indicate that the main fuel is fat.

In cooperation with Dr. Paul K. Dayton's benthic ecology group, Dr. Kooyman assessed benthic life under Antarctic shelf ice. His interest stemmed from the 1981 Weddell seal study at White Island, where it was noted that despite the thick ice, there must be considerable fish productivity to support the food needs of the seals.

Another study determined the diving activity of female leatherback turtles fitted with time-depth recorders. Diving activity was measured during the 10-day period between nestings. Results suggest that turtles' foraging behavior and physiological limits of diving may have some intriguing similarities to those of diving mammals.

Visibility Laboratory

Research in environmental optics, digital image processing, and optical remote sensing receives major emphasis at the Visibility Laboratory.

New techniques for measuring optical attenuation properties in ocean water were developed by Theodore J. Petzold and Gerald D. Edwards in conjunction with Roswell W. Austin. A model of spectral attenuation properties of ocean water, developed by Austin and Petzold, allows the estimation of the complete spectral nature of the diffuse attenuation coefficient from a knowledge of that property at any single wavelength.

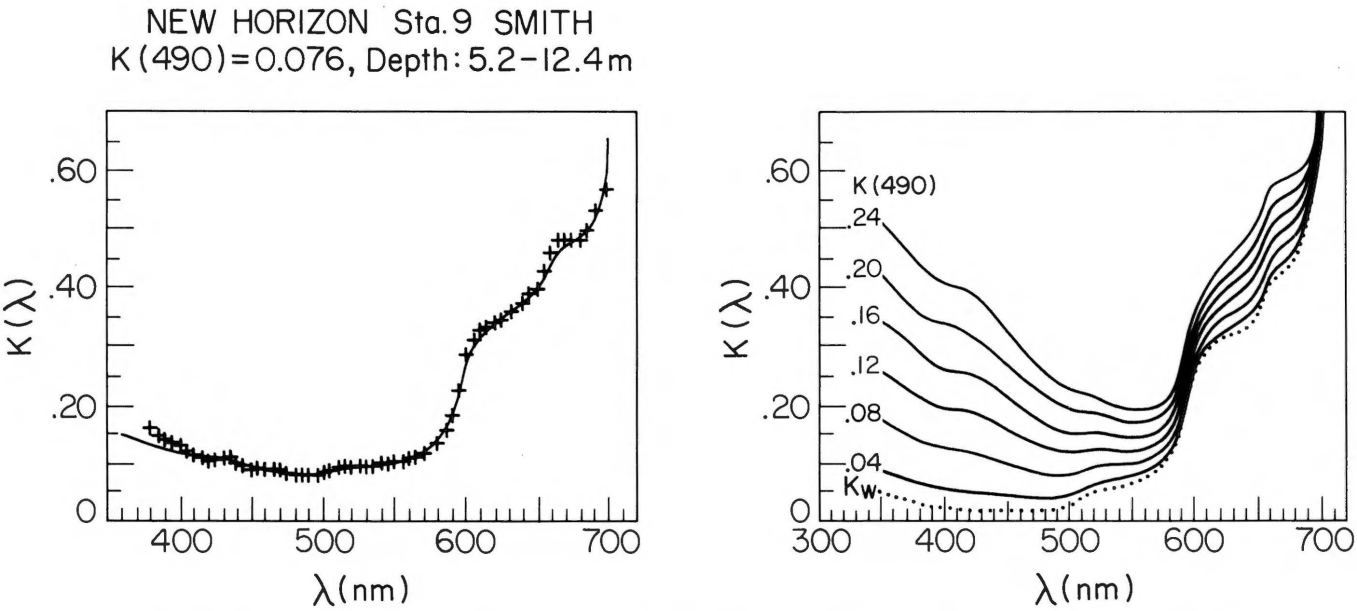
ROSWELL W. AUSTIN calibrates an instrument to measure light-attenuation properties of ocean water.

A technique for determining the optical properties of surface ocean waters using satellite data is being developed under the direction of Benjamin L. McGlamery. The goal is to provide seasonal maps of the diffuse attenuation coefficient, K, for the Northern Hemisphere Pacific and Atlantic oceans.

Data from the Nimbus 7 satellite Coastal Zone Color Scanner (CZCS) is being used to derive the K data. New data extraction procedures have been developed that allow interactive selection of the CZCS data and storage of that data in a rapidly accessible form for a variety of scientific calculations.

The Visibility Laboratory's program of theoretical and experimental research into the structure and behavior of atmospheric optical properties has engendered a computationally fast atmospheric scattering model (now designated FASCAT). FASCAT will be used to determine the apparent spectral radiance of distant objects and backgrounds. The field-oriented model developed by Wayne S. Hering uses conventional meteorological observations and environmental data to calculate directional path radiance and beam transmittance along any predetermined slant path in clear and cloudy atmospheres. Additional modeling techniques provide calculations of the inherent object and background radiances and, in turn, the apparent object-background contrast at the point of observation.

The requirement for additional validation data, particularly during intervals characterized by variable and fractional cloud cover, has prompted the development of a new instrument system under the supervision of Richard W. Johnson. The new, solid-state scanning radiometer is being built to acquire and analyze full-hemisphere radiance distributions. These will be used to continue validation of FASCAT predictive computations, and to develop new cloud discrimination and classification algorithms. Prototype versions of the radiometer system and its microprocessor have been tested and evaluated by Janet E. Shields and John S. Fox, with good results. Continued development is anticipated, with extension of the model-machine's performance into the regime of increasingly turbid environments under both day and night illumination levels.



Left, **A COMPARISON of modeled water characteristics (solid line) with attenuation measured in the field (+).** ***Right,*** **PLOTS of the dependence of the modeled attenuation properties on wavelength for waters of various clarity.**

Center for Coastal Studies

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

Dr. Douglas L. Inman, CCS director, studies fluid-sediment interaction, including feedback mechanisms among fluid forcing, bedform response, and sediment transport. His current research covers oscillatory bursting, thickness, and shear in the fluid-sediment boundary layer associated with carpet-flow; bedform geometry and response; and how each process interacts with the waves that force it. Among these processes, Dr. Inman identified several feedback mechanisms that appear to control the temporal and spatial scales of nearbed phenomena. This led to genetic classification of bedforms and to a general theory of bedform response.

Dr. Clinton D. Winant conducted a physical oceanographic study of the Gulf of California in conjunction with other scientists from Scripps and Mexico. Their work relates to circulation in the Gulf of California, which is a typical example of a marginal sea. A number of marginal seas have simple morphologies—long and narrow with two continental shelves separated by a deeper part. Thus, the main question becomes: Is circulation across the sea coherent, or do unrelated motions take place on either side? A pilot experiment indicated that the latter description is more appropriate, but the detailed experiment currently deployed will provide a more complete answer.

Dr. Scott A. Jenkins is developing sediment management techniques. He is working on a theory for the distribution of vertical shear stress within the floc layer, which settles in dredged estuarine harbors. The floc layer transfers stresses from a hull to the consolidated bottom, thereby interfering with ship maneuverability and increasing resistance in shallow water. Field measurements of shear-strength profiles, and concurrent sediment-concentration profiles within the floc layer are used to establish kinematic and dynamic boundary conditions on a model yielding gradient corrections to Einstein's (1906) original shear stress theory.

N. A. Bray

MEXICAN AND AMERICAN scientists aboard R/V *El Puma* during a physical oceanographic study of the Gulf of California.

Dr. Jenkins worked with the Mare Island Naval Shipyard to build, install, and monitor an array of lifting bodies that prevent siltation under berthed nuclear submarines. He traveled to the Mayport Naval Station in Florida to dimension a proposed venting canal, which will normalize sea-level inequalities and thereby reduce sedimentation rates in a turning basin. He also visited Charleston Naval Station to study circulation and sedimentation in the cells formed among finger piers.

Dr. Robert T. Guza's group worked on fluid mechanics of the surf zone. Graduate student Joan M. Oltman-Shay successfully used data-adaptive, high-resolution spectral estimators in a study of surf beat (nearshore waves with periods ~ 200 sec). Low-mode edge waves are found to dominate the surf-beat longshore velocity field. Graduate student Stephen L. Elgar is investigating the importance of nonlinear effects in shallow-water wave groups and other wave statistics. Field work in the Gulf of California is aimed at understanding how shelf-wide flows affect the motions occurring on the innermost shelf (depths less than 20 m).

Dr. Reinhard E. Flick developed instrumentation and deployment procedures for measuring turbulence fluctuations under breaking waves. He hopes to describe the spatial distribution of turbulence in the surf zone and to study how these high-energy fluctuations relate to the waves that produce them.

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

In the Hydraulics Laboratory, a 16-m tilting Plexiglas oscillating-flow water tunnel was completed. This unique facility, designed for studies of fluid mechanics and sediment transport, is capable of water-particle excursions of 2 m at a variable frequency to .33 Hz generated by an electrohydraulic servo piston, which can receive input of complex frequencies and variable amplitudes.

A major refurbishment of the 10-m, deep-ocean-environment simulation tank has been completed. Improvements include large viewing windows, a computer-controlled lighting system for solar simulation, and a thermistor chain to measure vertical temperature distribution.

Coastal adaptations of prehistoric southern California peoples are being studied in three different projects by Dr. Patricia M. Masters, coordinator of the Marine Archaeology Program. The mapping survey of submerged marine artifacts continues, and 42 sites have been recorded for San Diego County and Santa Catalina Island. This brings the total known submarine prehistoric sites in the Southern California Bight to more than 100. Second, a campsite discovered below mean sea level at La Jolla shores has been radiocarbon dated to 640 ± 90 BP and is yielding information on fishing and the seafood eating patterns of the late prehistoric Kumeyaay Indians. In the third project, the contribution of marine foods to the diet of the earlier La Jollan Indians (4000-8000 years BP) is being assessed by $\delta^{13}C$ and $\delta^{15}N$ isotopic analyses of amino acids extracted from skeletal remains.

Deep Sea Drilling Project

"AT 2400 HOURS 20 NOV 1983 THE DRILLING VESSEL GLOMAR CHALLENGER *WAS RETURNED TO GLOBAL MARINE INC. AND RETIRED FROM SERVICE TO THE DEEP SEA DRILLING PROJECT . . . PETERSON"*

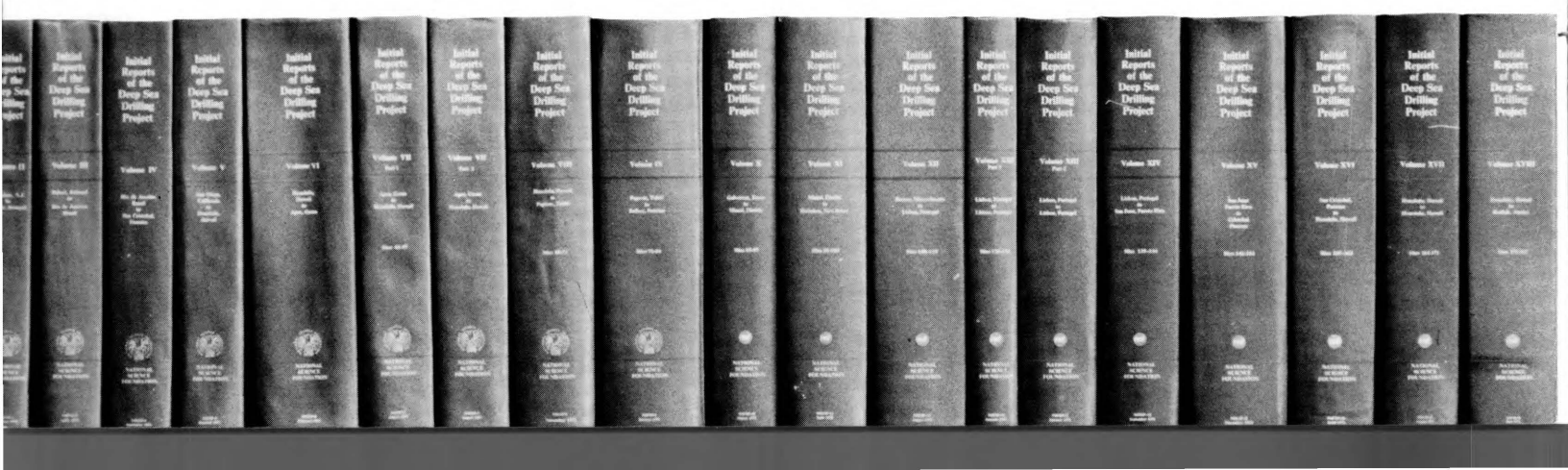
So ended 15 years of scientific ocean drilling and the unique floating seminar that had focused a worldwide scientific community on the advancement of earth sciences.

The major topics of changing world environments and developing physiography of the continental margins and ocean basins were addressed by the scientific teams of the final three DSDP cruises when they explored targets in the North Atlantic Ocean and the Gulf of Mexico.

Cenozoic environmental studies complement those undertaken earlier in the central and western Pacific. Work at these environmentally sensitive and geographically distant regions allowed earth scientists to view changing Cenozoic climates and environments on a global scale.

Ice Age Climates

The onset of the Ice Age in the Northern Hemisphere signaled a dramatic change in the climatic pattern of the earth: the uniformly warm climate that had prevailed for tens of millions of years gave way to an oscillating climate marked by periods of cold (glacial) and warm (interglacial) temperatures. On the basis of lithologic changes in samples from the climatically sensitive northeast Atlantic Ocean, leg 94 scientists confirmed that a major climatic shift occurred 2.4 million years ago, marking the beginning of a major glaciation period in the Northern Hemisphere.



The sediments also revealed evidence of strongly cyclic climatic changes that appear to occur at intervals similar to earth's orbital periods: 100,000, 41,000, and 23,000 years. The evidence supports the view that Ice Age climates are somehow related to the obliquity and orientation of the earth's axis.

Origin of Seafloor Features

The origin and development of major features on the North Atlantic seafloor were investigated by leg 94 scientists. They cored sediment wave fields on two major North American drifts—Feni and Gardar—and were surprised to find that the drifts comprise typical marine sediments, rather than the expected land-derived silt. Despite conjecture that the drifts move across the seafloor in much the same way that sand dunes move across the desert, the team detected no evidence that the drifts are now migrating.

Numerous hypotheses have been presented to explain the origin of King's Trough—a region of high (2 km) ridges separated by deep troughs. Cores taken during leg 94 showed that the region was once a major ridge, indeed an ancient island chain, built up over an unusually active volcanic center. Pieces of the newly formed seafloor were subsequently subjected to a series of rifting episodes—in a process that ended over 16 million years ago—and sunk well into the ocean crust to form the present parallel troughs.

The U.S. East Coast Continental Margin

The eastern coast of the United States, probably the most extensively studied region in the world, is slowly accumulating sediments that hold both a detailed record of an evolving passive margin and the potential of a petroleum reserve. During leg 95, scientists completed drilling a series of sites (the New Jersey transect) linking nearshore wells drilled by industry and the U.S. Geological Survey to those drilled offshore by DSDP on the continental rise. Recovery of highly resolved sections from key locations has helped workers to calibrate the vast network of seismic lines that blanket the area, and to reconstruct the geological development of the continental slope and rise.

Researchers also detected several major gaps in the sediment record that could be related to major geologic events. The largest gap (between middle Eocene and middle late Miocene, and encompassing 30 million years) corresponds to the initiation of the Circumpolar Current at the time when Australia broke away from Antarctica. Although data to support theories of global sea-level change were inconclusive, the scientists did detect considerable evidence of fluctuating shorelines and extensive channel cutting during low stands of the sea.

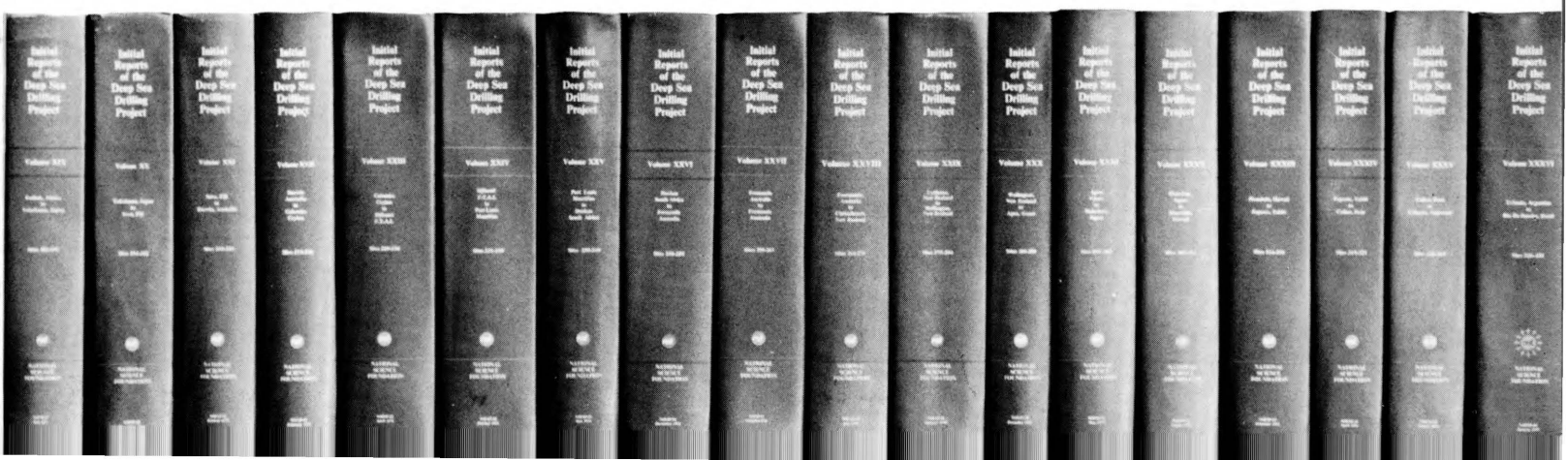
The Mississippi Fan

As potential sources of hydrocarbons, deltaic deposits and fan-shaped deep-sea deposits have long intrigued land-based geologists. Direct sampling of an actively building marine fan, however, awaited *Glomar Challenger's* probe on her last DSDP cruise. Attacking the complex three-dimensional puzzle posed by the rapidly growing and changing Mississippi Fan, leg 96 scientists studied cores from 11 sites on the middle and lower fan regions. They discovered that the fan is cut by a large submarine channel, which serves as a major conduit to carry coarse-grained sediments far offshore. In contrast, traditional models of deltaic deposition presume coarse-grained sediments to be deposited nearshore, and increasingly finer-grained sediments, farther offshore (as the river loses its hydraulic head and sediment-carrying capacity).

Leg 96 researchers also found slumping and gravity flow to be major mechanisms of sediment transport and deposition on the fan. Lowered sea levels, during periods when large volumes of water were tied up as continental ice sheets, allowed sediment deposits to build seaward along the continental shelf. Such deposits are particularly subject to slumping; as a result, most of the Mississippi Fan was built during the last ice age.

Intraslope Basins

The leg 96 team found contrasting depositional mechanisms at work in two small basins (Orca and Pygmy) on the northern slope of the Gulf of Mexico. Flanked by steep slopes of adjacent salt domes, the highly saline and anoxic Orca Basin is the site of massive slump deposits. There sci-



entists found small pebbles of gas hydrate in the gassy mud deposits. Sediments in the nearby (oxygenated) Pygmy Basin, however, settled slowly from suspension in the water column. (Recovery of an abundant and well-preserved Pleistocene microfossil sequence from the Pygmy Basin will help paleontologists create a Pleistocene reference section for the Gulf of Mexico.)

Tools and Technology

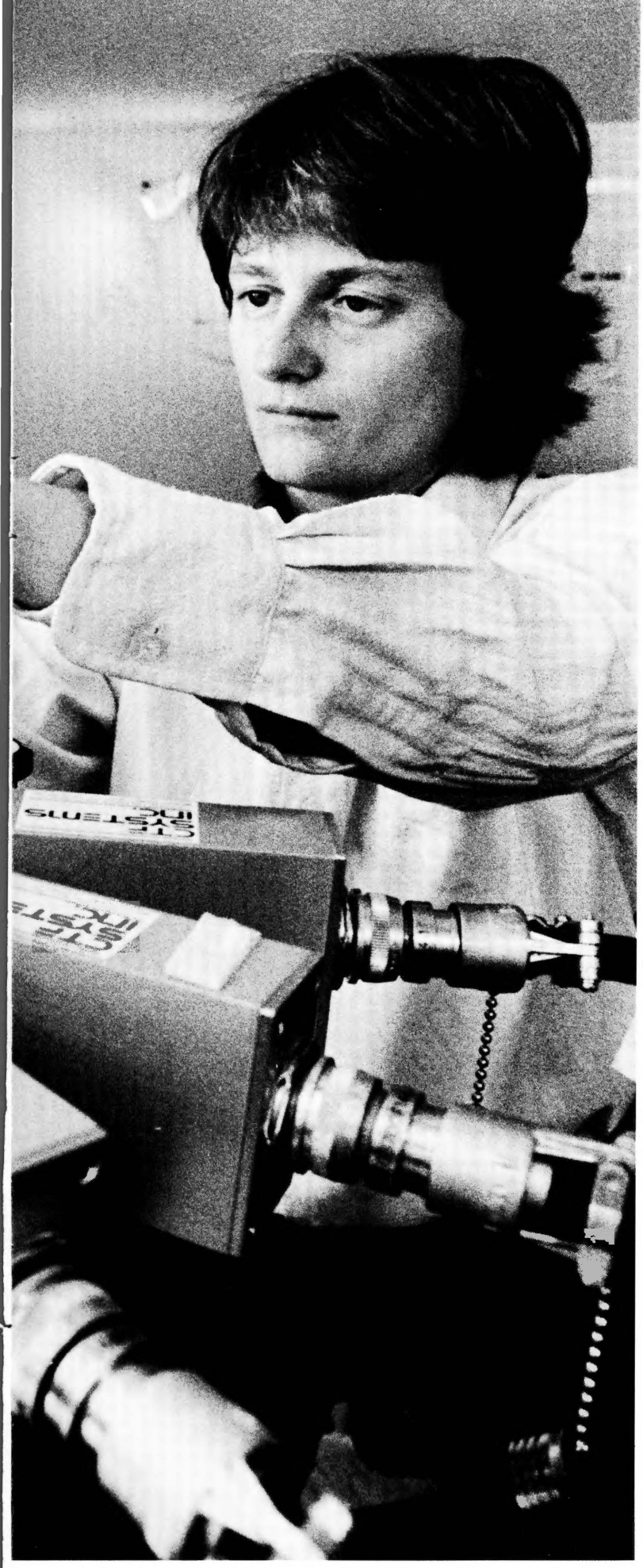
This year project engineers developed a new generation piston corer: the *advanced piston corer* (APC). Designed for greater efficiency, the APC has a more powerful stroke than the hydraulic piston corer, allowing greater penetration into firm sediments. Its shorter assemblage also makes it much easier to handle on deck.

Bare-rock drilling capabilities—desperately needed if scientists are to understand the geologic and chemical history of newly formed ocean crust—were addressed by DSDP engineers. They developed several theoretical models that would allow spudding the bit into a variety of seafloor environments and configurations. Their most promising concept incorporates the deployment of a gimbaled reentry cone that rests upon a weighted base plate. In such an assemblage, the drill string is prevented from "walking" on the seafloor, and the reentry cone remains vertical to receive and guide the suspended drill string despite a sloping or "bare" seafloor.

Science Services

The DSDP Information Handling Group reduces and encodes data and expediently processes requests for DSDP data and information. Staff at the West and East Coast repositories supply qualified researchers with appropriate sample material. Samples from legs 87 to 94 were made available for the first time during the past year.

DR. LISA TAUXE inserts a paleomagnetic sample into a cryogenic magnetometer for magnetic analysis.



Geological Research Division

The work of Geological Research Division scientists encompassed paleooceanographic and paleoclimatic studies, geochemical studies related to earthquake prediction, investigations of the physical properties of seafloor sediment, and geological/geophysical studies of Southwest Indian Ridge.

The paleooceanography group—Drs. Wolfgang H. Berger, Robin S. Keir, John S. Killingley, and Edith S. Vincent—investigated deglaciation, carbonate dissolution, and Miocene ocean history.

A new chronology for deglaciation (and hence sea-level change) was established. This chronology, which proposes deglaciation in two major pulses, or steps, centered on 13,000 and 9,500 years ago, is in excellent agreement with the sequence of climatic change documented for northern latitudes. Thus it will allow a better assessment of deglacial changes in atmospheric CO_2 content, as seen in ice cores.

Carbonate dissolution has greatly increased in the deep Pacific during the last few thousand years. The reverse seems to have happened in the Atlantic. The paleooceanography group thinks that the production of North Atlantic deep water may have greatly increased recently, parallel to secular cooling and desertification.

The mid-Miocene stable isotope record of the deep sea is characterized by a large excursion of $\delta^{13}C$ toward heavy values. From geochemical balance calculations it appears that this excursion reflects buildup of organic carbon within the Monterey Formation and contemporaneous deposits. An amount of carbon roughly equivalent to one oceanic carbon mass is involved in the buildup.

Paleooceanographic studies by Dr. Hans R. Thierstein and graduate student Timothy J. Bralower suggest that the global deposition of organic carbon-rich sediments during the mid-Cretaceous (90-120 million years ago) was accompanied by relatively low surface-water productivity and by slow global deep-water renewal. In association with Dr. Thierstein, graduate student Charles K. Paull developed analytical techniques to demonstrate that significant vital effects exist in the stable isotopic fractionation of different calcareous nanofossil taxa. The techniques also showed that ^{14}C ages of calcareous phytoplankton skeletons are often significantly different from the ^{14}C ages of foraminifera in the same late Pleistocene carbonate-ooze sample. The causes of these apparent age differences are currently under investigation.

Dr. Thierstein and graduate student Scott J. Hills initiated a research project on geometric shape analysis of marine microfossils. A computer-based image analysis system has been established and the necessary software developed to use the best fossil record available to study biogeographic and evolutionary morphologic variability of groups of extant organisms.

Dr. Devendra Lal reports a general consensus that the earth's geomagnetic dipole field varied by about 50 percent during the past 8,000 years. This is supported by the ^{14}C data in tree rings and by archeomagnetic data. A closer examination shows that the latter evidence is weak; the primary evidence is the radiocarbon tree-ring data. However, sensitivity studies carried out by Dr. Lal on the the carbon cycle's response to climatic changes, and the expectations for the past $(8\text{-}10) \times 10^3$ years have now cast severe doubts on the ^{14}C evidence for geomagnetic dipole field change. It now appears that the geomagnetic field change was much smaller than believed.

Dr. Lal proposed several new applications of the cosmic-ray-produced isotope ^{10}Be. One application is the measurement of changes in cosmic-ray intensity, which in turn may relate to changes in the geomagnetic dipole field during the past several millenia. The method involves measuring ^{10}Be activity in tree rings and in documented stone samples, such as Sphinx and pyramidal stones. Other applications of cosmic-ray-produced ^{10}Be include the study of mountain-building processes (uplift and erosion rates) and glacier movements.

Dr. Yu-chia Chung continued his geochemical studies of radon, helium, and other parameters in hot springs and thermal wells for earthquake prediction in southern California. Emphasis was placed on installing and operating Continuous Radon Monitors at major network sites for real-time radon monitoring.

In December 1983 Dr. Chung visited the State Seismological Bureau in Beijing, China, to discuss cooperative geochemical studies in selected seismic zones.

Dr. LeRoy M. Dorman and graduate student Allan W. Sauter completed field work on a study of the physical properties of the upper tens of meters of the seafloor, and the effect these properties have on signals recorded by ocean-bottom seismographs. The seafloor properties are studied by analyzing the dispersion (dependence of propagation velocity on frequency) of Stoneley waves (interface waves traveling along the seafloor) generated by small seafloor explosions. These waves are characterized by extremely low speeds (30 m to 100 m per second) resulting from the low shear strength of seafloor sediments. The seafloor structure derived from analysis of Stoneley waves will be compared with that derived from the wide-angle reflection of air-gun signals.

The high compliance of the seafloor can cause resonances resulting from presence of an instrument, and these resonances can alter the signal seen by the instruments. The researchers seek evidence for these resonances in the recordings of the instrument's motions caused by an internal shaker. The shaker experiment has been performed on land as well as on the seafloor, and at room and seafloor temperatures. If these resonances can be defined with the use of an internal shaker, this experiment can be performed routinely on the seafloor. The results will be useful in correcting recorded seismic signals to obtain the seafloor motion that would occur in the instrument's absence.

Dr. Robert L. Fisher served as overall planner and cruise coordinator of the eight-month, multidisciplinary PROTEA Expedition to the Southern Hemisphere aboard R/V *Melville*. Dr. Fisher directed a 31-day exploration from Cape Town to Cape Town, which emphasized recovery of lower crustal and upper mantle ultramafic and mafic plutonic rocks from deep cross-fractures, and fresh extrusive rocks from crestal regions of the very slowly spreading Southwest Indian Ridge. This exploration was sponsored by the National Science Foundation's Division of Polar Programs. With additional senior participants from U.S. and South African institutions, this operation completes the Indian Ocean ridge system plutonic rock sampling begun by Drs. Fisher and Celeste G. Engel in 1968. Detailed geophysical, geochemical, and petrologic study, and publication of the extremely varied PROTEA materials will involve Drs. Fisher and James H. Natland and their American and South African colleagues.

The new Scripps paleomagnetic laboratory houses equipment for measuring magnetic properties of geologic samples in a room virtually free of the effects of the earth's magnetic field. The laboratory features a CTF cryogenic magnetometer, a Molspin fluxgate spinner magnetometer, alternating field and thermal demagnetizers, a Sapphire instruments susceptibility bridge, and a Kirschvink impulse magnetizer. An IBM Instruments S9000 computer, interfaced with both magnetometers and the susceptibility bridge, is used for data acquisition, reduction, and storage.

Research in the laboratory, directed by Dr. Lisa Tauxe, covers topics that include the properties of chemical remanent magnetism, cyclic variations of magnetic and isotopic signatures on the Oligocene, high-resolution stratigraphy in Miocene molasse deposits in Pakistan, and magnetic stratigraphy of mammal-bearing sediments in the rift valley of Kenya.

Marine Biology Research Division

Marine Biology Research Division scientists continue to investigate the ecological, physiological, cellular, and biochemical characteristics of marine bacteria, plants, and animals. These studies range from an examination of egg and sperm interactions in marine invertebrates to research into how small clams of the genus *Xylophaga* use sunken wood as food.

Dr. Victor D. Vacquier's group is studying proteins in the sea urchin sperm plasma membrane that mediate the interaction of sperm and egg at fertilization. The investigators have identified one protein as the enzyme guanylate cyclase. This protein, a major component of the sperm membrane, is constitutively phosphorylated before sperm meets egg. When the sperm touches the egg the cyclase instantly dephosphorylates and decreases its catalytic activity about 40-fold. The researchers found that a nucleotide cyclase is regulated by its state of phosphorylation.

Another sperm membrane protein, called 210K, which is a regulator of the sperm acrosome reaction, was found by Dr. Vacquier's group. Antibodies to the 210K block the normal influx of calcium and the efflux of protons that occur when the sperm contacts the egg. The researchers conclude that 210K is a regulator of the ion channels in the membrane, which must operate in the activation of the sperm by the egg. Thus sea urchins have become an important model system for defining the role of sperm membrane proteins in the fertilization process.

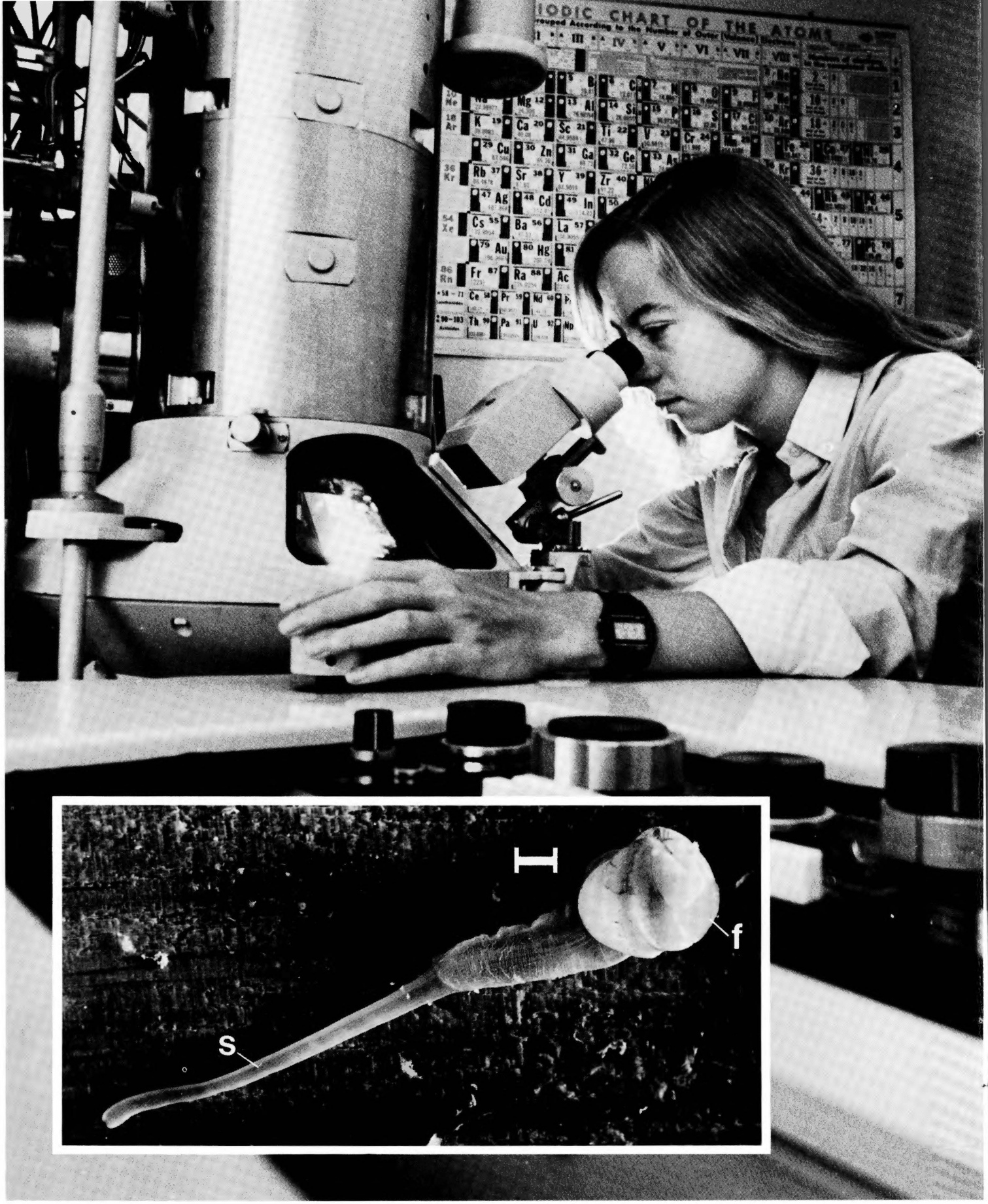
In Dr. Andrew A. Benson's laboratory, the effects of acid rain on gill membranes were studied collaboratively with Dr. Judd C. Nevenzel. Membrane structure can be extremely sensitive to high acidity (low pH), an effect that may be caused by large amounts of plasmalogen, an acid-labile phospholipid, in membranes. Gills of marine crustaceans can have up to 95 percent of their phospholipids in the forms of plasmalogens.

The element arsenic is the focus of a study by Drs. Benson and Francis C. Knowles. Arsenic, ubiquitous in seawater, is metabolized by all aquatic plants, with the formation of arsenoribosides. Their biosynthesis and metabolism demonstrate the mechanism of arsenical toxicity. This study clarifies arsenical drug action; such drugs are used for treating diseases caused by blood parasites.

Acoustic measurements of a seamount in the Gulf of California (El Bajo Espíritu Santo) were made by Dr. A. Peter Klimley as a first step in a study of pelagic fish orientation. Dr. Klimley determined at what distance acoustics could be used by scalloped hammerhead sharks *(Sphyrna lewini)* to home to the seamount. In collaboration with Dr. Adrianus J. Kalmijn, Dr. Klimley measured another potential cue for finding the seamount—geoelectric fields.

Spawning and bioluminescence in the polychaete worm *Odontosyllis phosphorea,* found in San Diego's Mission Bay, are under study by Dr. Frederick I. Tsuji. Shortly after sunset the worms appear at the surface, where they pair and mate, producing bursts of luminous secretion and gametes. The males swim in relatively straight lines, whereas the females move in tight, wiggling circles, each leaving a bluish luminescent trail. Within an hour the worms disappear from the water. The study shows that there are three rhythmic components in the reproductive behavior of the worm: a seasonal cycle, with peak spawning in the warm-water months of July to October; a fortnightly cycle, with spawning corresponding roughly with the first and last quarter phases of the moon (and hence with neap tides); and a strong daily cycle, with spawning confined to less than an hour, beginning shortly after sunset. The study suggests that regardless of proximate factors, the behavior of the worms in Mission Bay is an adaptation to tidal conditions that recur at fortnightly intervals.

Dr. William A. Newman finished an analysis of the Hawaiian biota and correlated the marked degree of amphitropicality (similar organisms on both sides of the equator) in the terrestrial as well as marine environment with the Pleistocene. In 1859 Darwin noted that cooler temperatures during the Pleistocene were important in understanding amphitropicality, but he was unaware that sea level had also fluctuated. During times of low sea level, low islands extending across the equator became high islands, and this



GRADUATE STUDENT SUSAN J. ROBERTS prepares to make transmission electron micrograph of *Xylophaga washingtona*, a wood-boring bivalve. *Above, X. washingtona* removed from its wood burrow. S = siphon, f = foot, scale = 3mm. *Right* is a scanning electron micrograph of the animal's shell, illustrating the denticulated ridges used to bore through wood. Scale = 100μm. *Far right* is a transmission electron micrograph of gill tissue containing the bacterial symbionts. ba = bacteria; sw = seawater; and bl = blood. Scale = 1.0μm.

may help explain the biotic similarities between Hawaii and the high islands of the South Pacific.

Field studies conducted by Dr. Joan G. Stewart are designed to discover the attributes of two species of *Phyllospadix* (surfgrass), an angiosperm, and several algal species that adapt these very different plants to share a habitat low in the intertidal zone. Experiments are under way on two major study sites to compare reproductive rates and vegetative growth rates, as well as morphological characteristics that allow these taxa to dominate a portion of the intertidal beach.

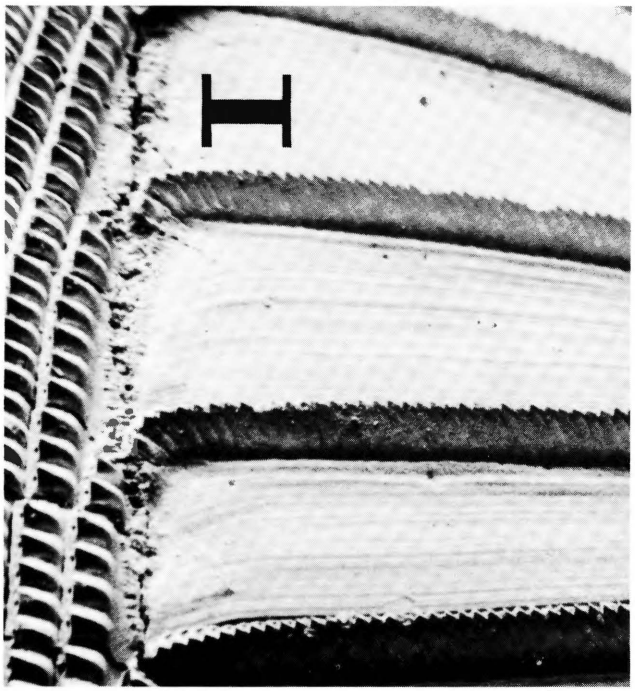
Dr. Claude E. Zobell continues work on the microbial transformation of hydrocarbons, with special reference to the oil pollution problem. He is investigating the microbial modification of chromium, lead, and nickel.

Dr. Ralph A. Lewin and his colleagues continue their studies of autotomy of algal flagella, the process by which unicellular algae such as *Tetraselmis* (marine) and *Chlamydomonas* (from fresh water or soil) shed their flagella under adverse chemical or physical conditions (such as low or high pH, and sublethal concentrations of certain chemicals). The function of flagellar autotomy is unknown, but the process is virtually universal among algal and fungal zoospores and similar flagellated cells.

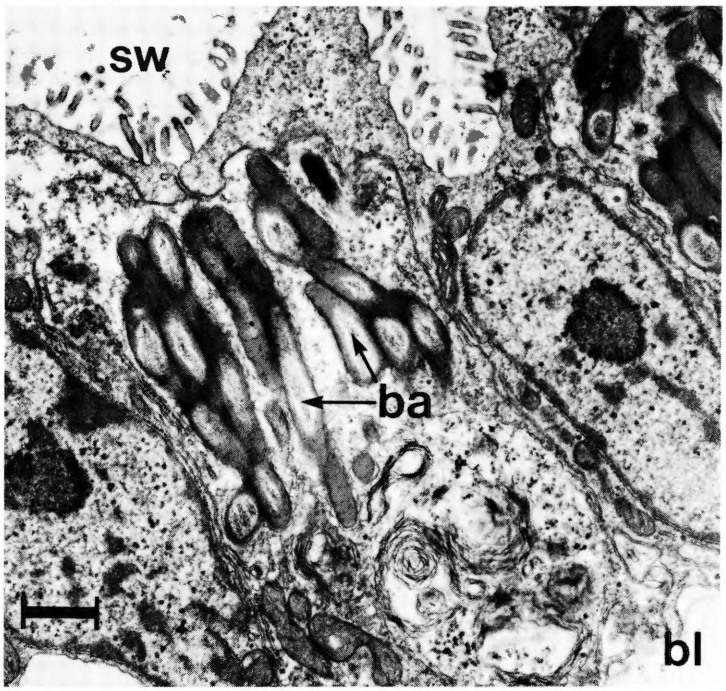
Autotomy always occurs at the bases of the flagella, at the level of the so-called transition bodies, which may be directly involved with the process. Electron microscopic studies indicate that autotomy involves a localized degradation of microtubules and matrix proteins in the abscission zone, followed by a pinching-off of the flagellar membranes. In the species studied by Dr. Lewin's group, divalent ions, notably calcium, are essential for the process; for marine flagellates, sodium ion also is implicated. Whether these ions are needed for a sensory mechanism, whereby adverse conditions are detected, or for the mechanical process of autotomy itself, remains to be determined.

Projects concerning the biochemical adaptations of marine organisms to their environments are under way in the laboratory of Dr. George N. Somero. Clams and tube worms from habitats rich in hydrogen sulfide (for example, the deep-sea hydrothermal vents and hypoxic basins off southern California) were the focus of one study. Researchers are examining how these animals protect themselves from poisoning by sulfide, a highly toxic substance, and how the symbiotic bacteria found in certain tissues of these animals exploit the energy of the sulfide molecule. The animals exhibit several types of sulfide detoxifying reactions, including a "peripheral defense" involving sulfide-oxidizing activities in the outer layers of muscle tissues. A sulfide-oxidizing enzyme system from the trophosome tissue of the hydrothermal vent tube worm, *Riftia pachyptila,* was isolated; this enzyme may be important in the energy-yielding conversions of sulfide to oxidized sulfur compounds. Dr. Russell D. Vetter studied the types of transformations encountered by sulfide taken up in animal-bacterial symbioses, with emphasis on the different sulfur metabolites and their localization within the organisms. The ways in which these newly discovered animal-bacterial symbioses survive in, and exploit, sulfide-rich waters is the focus of this work.

A second symbiont-containing animal system was studied by graduate student Susan J. Roberts. The amazing success of the wood-boring bivalve *Xylophaga washingtona* in colonizing a transient habitat (sunken pieces of wood) is the focus of her investigation. Panels of wood were placed 274 m deep in Scripps Canyon and were recovered 50 days later heavily infiltrated by *Xylophaga.* Xylophagid larvae



S. J. Roberts



S. J. Roberts

settle on the wood and begin burrowing into the wood as they metamorphose into the adult form. The ability of these bivalves to locate and colonize pieces of wood that have been channeled into ocean basins and canyons is partially a function of their capacity to produce and disperse large numbers of larvae. Males and females as small as 0.85 mm have been found with mature sperm and eggs. Using a growth rate estimated from the size of the largest individual and the known exposure time of the wood, *X. washingtona* can be expected to reach sexual maturity 10 days after penetrating the wood. Members of the Xylophagainae mature as males and after their first sexual phase may either remain males or change into females. Both sexes have *vesiculae seminales,* structures in which sperm are stored. Such structures are rare in bivalves and may be a specialization to allow self-fertilization. This would be a useful adaptation for a species that exploits such a scarce and isolated habitat as wood in the deep sea.

Another key to xylophagids' success involves their ability to digest wood. The shells of xylophagids have denticulated ridges for rasping wood, and the clams hold wood chips in a caecum for digestion. The enzymes needed to digest wood and supply the clams with fixed nitrogen may be provided by bacterial symbionts found in the clam's gills. These bacteria can degrade cellulose and fix nitrogen in culture, and appear critical to the clam's nutrition. How the clams acquire their bacteria is currently under study.

Ecological energetic studies of deep-sea communities continue in the laboratory of Dr. Kenneth L. Smith. Estimates of the organic carbon demand by the benthic boundary layer are currently being compared with the supply of particulate organic matter from the overlying water column. Dr. Kenneth E. Richter is developing a free-vehicle acoustic array to count and monitor movements of deep-sea animals. He will then evaluate their role in active transport of organic matter. Dr. Raymond R. Wilson is studying the swimming dynamics of abyssal fish *Coryphaenoides armatus* and *C. yaquinae* using a free-vehicle video system. Graduate student Waldo W. Wakefield initiated studies on the importance of planktotrophic development of demersal species in transporting organic matter through a bathyal water column.

Dr. Benjamin E. Volcani's group studied silicon's function in metabolism, regulation of gene expression, and cell-wall morphogenesis in diatoms. Dr. J. Richard Ludwig cloned genomic DNA and cDNA derived from the diatom *Cylindrotheca fusiformis,* and is isolating and characterizing specific genes whose expression is regulated by silicon. Dr. Chia-Wei Li found bacterial symbionts in *Odontella sinensis* and *O. regia* and isolated the bacterium that was found to fix nitrogen. Dr. Baruch Rinkevich studied morphogenesis of the radula of the limpet *Lottia gigantea,* with special emphasis on biomineralization of silicon and iron. UC San Diego graduate student Christopher D. Reeves completed his studies on the effects of silicon on gene expression, finding that silicon affects the level of phosphorylation and dephosphorylation of individual proteins.

Marine Life Research Group

The California Current is complicated and variable in both its physics and its biology. Occasionally there are extreme conditions that merit special attention because of their magnitude, and because the ecological consequences reveal how marine ecosystems may be regulated and altered.

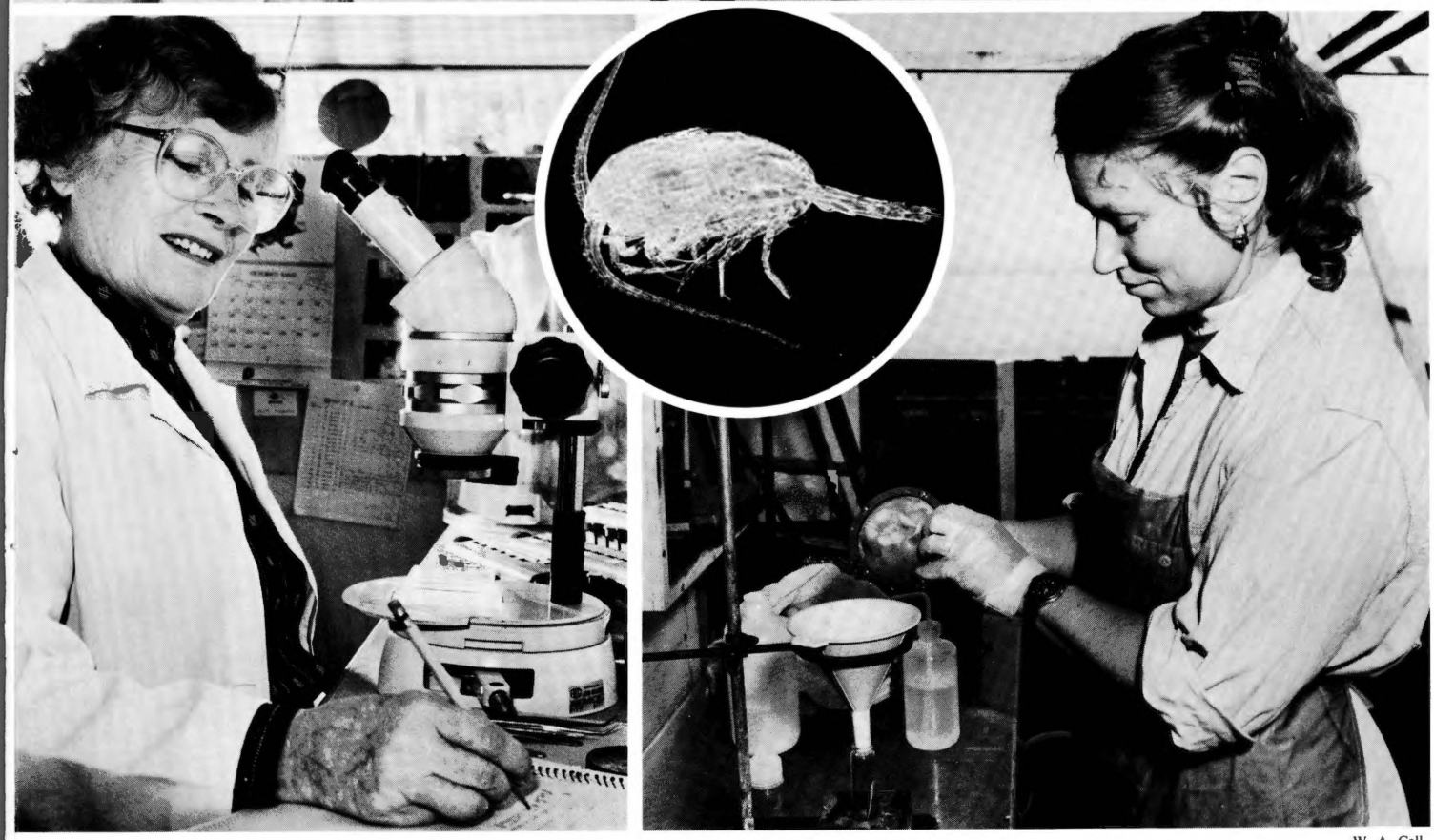
Such an episode occurred during 1957–1959, when the current system was anomalously warm and salty, and had a weakened southward flow. This resulted in a great reduction in the carrying capacity for zooplankton.

The 1957–1959 anomaly coincided with a major climatic event, an equatorial El Niño. Between 1957–1959 and 1982 there were four moderate-to-strong El Niño events along the equator, but little or no evidence of them in the California Current. Another large equatorial El Niño event (now called ENSO for El Niño-Southern Oscillation) developed in mid-1982, and it became clear that the California Current was responding.

Marine Life Research Group (MLRG) investigators recognized the early signs, and concluded that a major warming, like that of 1957–1959 was about to occur. Drs. John A. McGowan, James J. Simpson, and Pearn P. Niiler, along with the MLRG staff, mobilized their resources and, with the additional assistance of the Office of Naval Research and the California Sea Grant College Program, began to study the California El Niño as it developed.

***Above,* JAMES P. COSTELLO, DR. LOREN R. HAURY, AND DR. THOMAS L. HAYWARD bring the Longhurst-Hardy Plankton Recorder aboard R/V *New Horizon* after taking zooplankton samples at a station in the California Current. *Below left,* Thea Schultz sorts and counts zooplankton species from plankton recorder samples. *Inset,* adult female of the copepod *Metridia pacifica. Below right,* Connie L. Fey bottles zooplankton samples.**

E. L. Venrick



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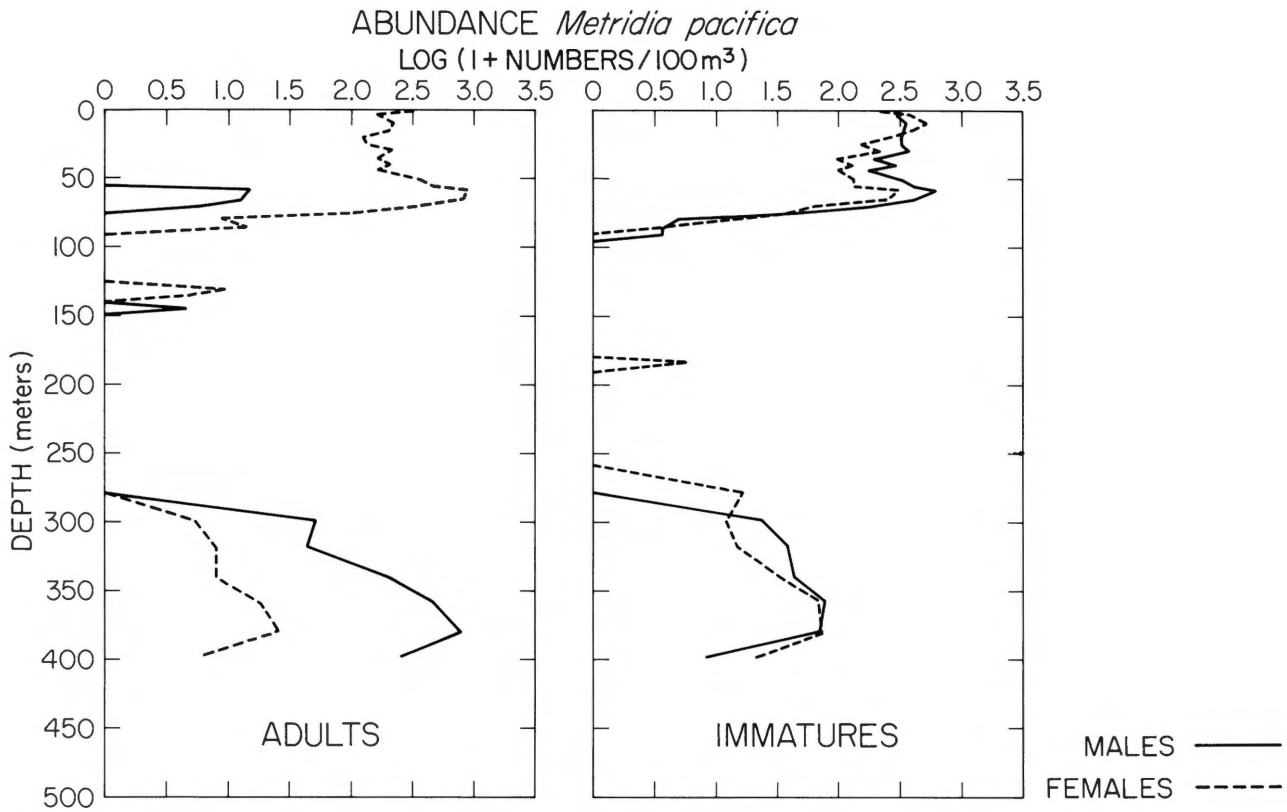


VERTICAL DISTRIBUTIONS of adult and immature stages of the copepod *Metridia pacifica* obtained from a Longhurst-Hardy Plankton Recorder tow taken at night in the California Current. Some immature males and females have migrated from their daytime depth of between 250 and 450 meters to feed in the surface waters. In addition, most adult females also migrate to the upper 100 meters at night. Almost all adult males, however, remain at depth. Other species of zooplankton might show very different patterns of vertical distribution and migratory behavior, depending on their life histories.

During twelve three-day cruises the physics, chemistry, and biology of the current were examined in considerable detail. Drs. McGowan, Simpson, and Niiler analyzed the resulting data and found the 1983–1984 California El Niño to be the largest on record, both in its spatial extent and in the magnitude of its subsurface temperature anomaly.

The normal spring-summer intrusion of warm, salty water from the southwest into the Southern California Bight was greatly enhanced in 1983. Offshore from this intrusion there is normally a large, biologically rich mass of cold, low-salinity water tending downstream from the north. This all but disappeared in 1983, and the remnants of its low-salinity core were crowded toward the coast by the western Central Pacific Gyre. The extraordinarily deep thermoclines and strong stability layers kept nutrients from being cycled up into the lighted surface zone. There was a failure of the spring-summer plankton bloom, and the amount of macrozooplankton, which pelagic fish eat, was reduced by a factor of ten.

Although Southern Oscillation-Kelvin Wave theory appears to satisfactorily explain equatorial El Niño events for some oceanographers, the characteristics of the California analog suggest that these theories are, as yet, imperfect.

Dr. Thomas L. Hayward continues studies on the physical processes that affect the large-scale nutrient distributions and the patterns of primary and secondary production in the North Pacific Central Gyre and California Current ecosystems. Production patterns are important aspects of ecosystem structure because they affect the species proportions and the yield available from higher trophic levels. His research involves collecting additional data at sea in the California Current as part of the CalCOFI program and on east-west transects across the North Pacific. Production in the central North Pacific is nutrient limited, and variations appear to be caused by large spatial scale changes in the vertical distributions of nutrients and physical structure. However, most of the production in the California Current is aggregated in a small fraction of the total area and appears to be caused by mesoscale physical forcing processes.

In related work, Dr. Elizabeth L. Venrick continues to study the ecology of phytoplanktonic species in the North Pacific Gyre. Her work focuses on vertical distribution shifts produced by a winter deepening of the mixed layer. In an attempt to understand the contribution, by size, of picoplankton (cells between 0.5 and 3 μm), chlorophyll has been extracted from samples filtered through GF/C filters (1.2–3.0 μm) and GF/F filters (0.7 μm). There is a nonlinear relationship between total phytoplankton and picophytoplankton. Approximately 15 percent of the chlorophyll collected on the finer filter in the oligotrophic Central Pacific Gyre results from picoplankton. In the more eutrophic California Current, the contribution of picoplankton to the total chlorophyll concentration is reduced.

A study of the similarities and differences in the ways that zooplankton use environmental space in the North Pacific Gyre and the California Current region is being carried out by Dr. Loren R. Haury. He is examining the vertical structure of zooplankton communities. In some cases, there are marked differences in the way a species or congener uses vertical space in the two ecosystems; in others, there is no apparent difference.

Dr. Kenneth L. Smith is investigating ecological energetics of deep-sea communities across the boundary between the oligotrophic North Pacific Gyre and the California Current region. Dr. Smith is comparing oxygen consumption by the deep-sea sediment-dwelling communities in the two zones and is relating it to the supply of particulate organic matter in the overlying water column. Early results suggest that oxygen consumption rates are higher under the eutrophic waters than under the oligotrophic waters.

Five scientists from other universities made observations in the fall of 1982 from a submersible. There in the Santa Barbara Basin, California, they found persistent aggregations of nonmigrating, stage V copepodites of *Calanus pacificus californicus* Brodsky in a band 20 ± 3 m thick at a depth of 450 m, about 100 m above the bottom of the basin. Dr. Abraham Fleminger then examined historic collections of discrete-depth plankton tows. Both the submersible observations and the net collections suggest that the dense aggregation of diapausing copepods observed in the Santa Barbara Basin was a phenomenon associated with seasonal upwelling cycles, and that such aggregations occur during nonupwelling periods when food is scarce in surface waters. Numerous predators, especially the deep-sea smelt *Leuroglossus stilbius*, were observed feeding upon the aggregated copepods; thus, in contrast to the conventional picture of surface-dominated food distribution, deep-water aggregations of *C. pacificus californicus* may support the mesopelagic community during periods of low food availability in surface waters.

Dr. Fleminger found unusual genetically controlled, sex-linked dimorphism in adult females of many calanid species. The dimorphism and morphometrics suggest that sex determination in calanids is under partial genetic control, but may be modified by environmental factors. The proportion of dimorphs in populations of calanids is highest in the spring, the most food-rich season, which suggests that food may be the determining factor. The morphogenesis of secondary sexual characters is mediated by hormones from the gonad or gonoducts.

Dr. Niiler is studying the general ocean circulation and its relationship to air-sea interaction in three research projects. He is undertaking a statistical analysis of 33 years (1950–1983) of ocean temperature and salinity data from the upper 500 m along a transect across the California Current. The orthogonal empirical functions (or principal components of variance) analysis shows that temperature and salinity have very different histories in the California Current. The largest variance of temperature is within the seasonal thermocline of about 75-m depth, and temperature is the warmest during El Niño episodes. The principal component of salinity variance, on the other hand, is governed by a factor that extends from 200-m depth and has a time scale unrelated to temperature. Thus, both salty and fresh El Niño events can occur in the California Current. Research continues to clarify these phenomena in terms of specific mechanisms of large-scale air-sea interaction in the eastern Pacific.

A second study involves moorings with nine current-sensors in the upper 2000 m and one sensor at 4000 m that have been deployed at 152°W, 28°N for three years. Analysis of the data from July 1982 to July 1983 shows an unexpected northward flow of 1.7cm/sec at 4000 m for the entire year. At 42°N a remarkable two-thirds of the intensity of time-variable currents at 4000 m can be accounted for by forcing that results from the surface wind-stress curl.

In a third program, seven drifting buoys with 200-m-long lines and 120-m thermistor chains were released along the Pacific equator in October 1983. Their position and subsurface temperature data are retrieved by the Argos satellite system. This longitudinal array senses northward buoy displacements propagating to the west at about 54 cm/sec and, while within two degrees of the equator, minor waves are seen in the temperature front north of the equator.

Arnold W. Mantyla and Joseph L. Reid continue their studies of general oceanic circulation by mapping and examining the characteristics (density, temperature, salinity, dissolved oxygen concentration, and silica) in the bottom waters of the world ocean. Although it is known that the coldest and densest waters at the bottom of each of the major oceans (abyssal waters) come from the Southern Ocean, their characteristics indicate that the major component does not derive directly from the abyssal Antarctic. Instead it comes from the shallower Circumpolar Water, which is a mixture of Antarctic Waters with the warm, saline, oxygen-rich, and nutrient-poor deep waters from the North Atlantic. As the Circumpolar Water extends northward it is modified by mixing with the overlying waters, which in the North Atlantic and North Indian oceans are more saline, and in the North Pacific less saline. The abyssal waters of the northeast Pacific are farthest from regions of ventilation and are the most nearly uniform; they may be the oldest of the abyssal waters.

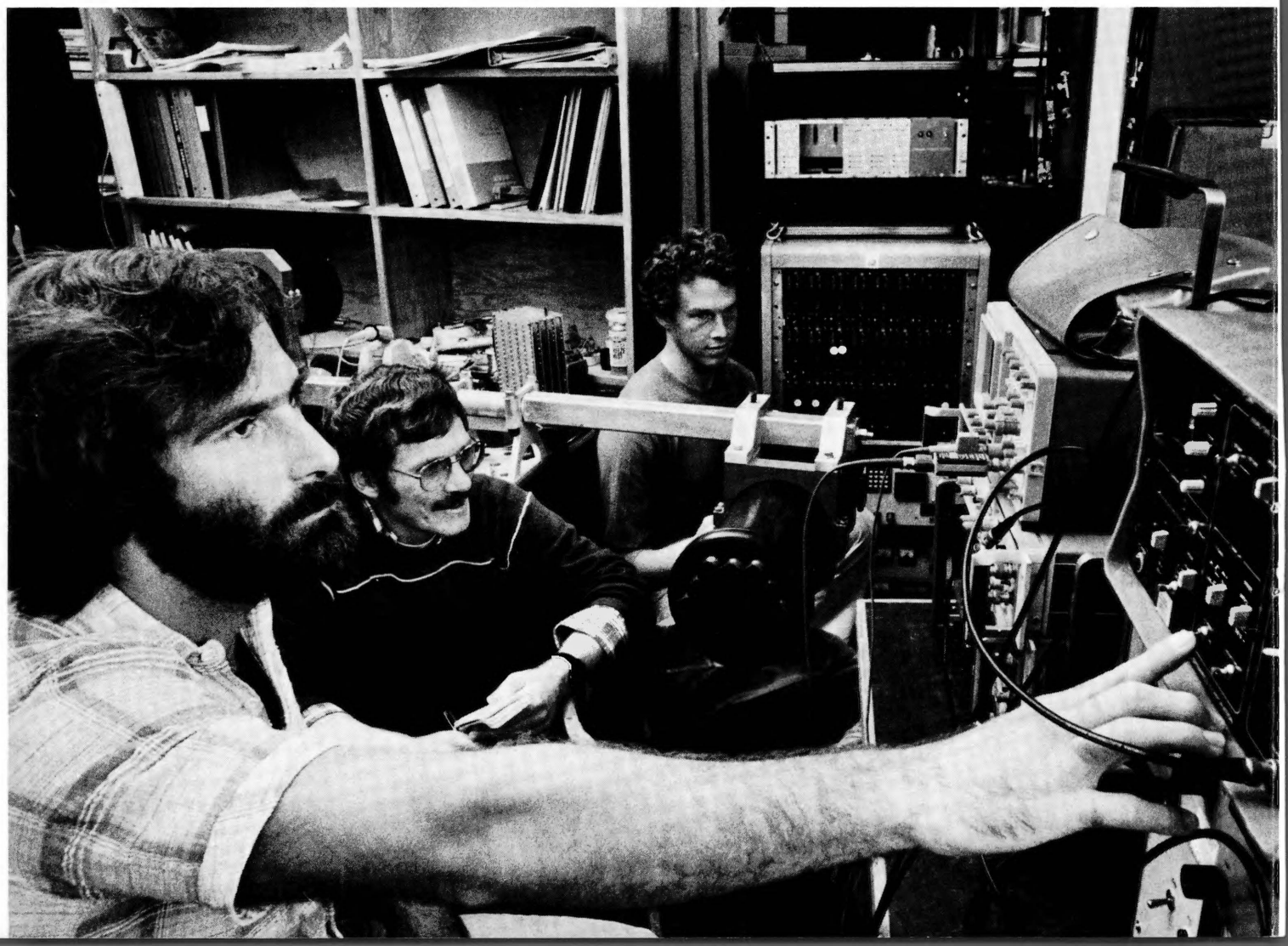
Dr. James H. Swift investigated mechanisms that could allow the highly stratified Arctic Ocean to become a significant source of deep and bottom water. He concluded that winter ice formation over the large shallow seas surrounding the Arctic Ocean probably feeds cold, brine-enriched waters into the abyss. The salty deep waters then flow southward through the Greenland-Spitsbergen Passage, where together with Greenland Sea waters they feed the deep Norwegian Sea. In other work, Dr. Swift identified source regions to the Denmark Strait overflow and demonstrated that the deep Northwest Atlantic Ocean can respond in as little as two years to a change in the surface waters north of Iceland. Dr. Swift's work on oceanic response to short-term climatic fluctuations continues with an examination of 20-year changes in the water masses of the Greenland Sea.

Marine Physical Laboratory

The research groups of the Marine Physical Laboratory (MPL), directed by Dr. Kenneth M. Watson, conduct investigations in ocean acoustics, marine physics and geophysics, signal processing, and ocean technology.

Dr. Watson and his group continue to study internal wave properties at near-inertial frequencies. Observations and theoretical analyses over the past ten years indicate that sources inject energy into the internal wave field at large spatial scales. Dissipation appears to occur at the smallest spatial scales. Calculations suggest that energy is transported by wave-wave scattering from large to small spatial scales. These calculations have not identified a mechanism, however, for this energy transport at near-inertial frequencies. A recent study shows that interactions of new inertial-frequency internal waves with mesoscale flows may provide such a transport mechanism. This work implies that the mesoscale currents provide a significant source of energy for the internal wave field.

Dr. Henry D. I. Abarbanel is working to clarify the transfer of energy and action from the oceanic mesoscale field to internal wave motions. He has focused on establishing stability theorems for mesoscalelike flows in the presence of background stratification. When the shear flow becomes un-



stable to perturbations, the perturbations—which are the internal waves themselves—will grow and carry energy out of the mesoscale motion. The nonlinearities of the flow will eventually stabilize the growth. Dr. Abarbanel investigated the stability of these flows to nonlinear deformations using a method developed in 1965 by the Soviet mathematician V. I. Arnol'd.

Dr. Abarbanel and two students explored the nature of friction by studying the coupling of a fast, high-frequency Hamiltonian setup, called the bath, to a slower, low-frequency Hamiltonian system called the system. They were interested in how the system behaves when the bath is (a) integrable, but has an infinite number of degrees of freedom or (b) nonintegrable and has only a few degrees of freedom. The common feature in the two model types is the presence of correlation functions in phase space that die away exponentially fast in time. When this occurs, dynamical information from the slow system leaks into the fast bath, and the system can appear dissipative on time scales long compared to the correlation time, and short compared to a recurrence time. This investigation applies to high-frequency motions, which take energy out of the mesoscale motions. The goal is to calculate the transfer coefficients for the rate of transfer of energy and momentum from system to bath.

Dr. Abarbanel is UC San Diego organizer for the University of California's systemwide Institute for the Study of Nonlinear Dynamics, founded to stimulate research collaborations among the diverse scientific interests throughout the university.

Dr. William R. Young is investigating the recirculation zones of both the Gulf Stream and the Kuroshio. The recirculation zones are regions of rapid westward flow that lie to the south and east of the Gulf Stream in the Atlantic and the Kuroshio in the Pacific. Although the narrow, intense flow has been relatively well characterized (at least in the Atlantic) there is little or no theoretical understanding of its dynamics. A preliminary theoretical investigation, which is motivated by a numerical model developed in collaboration with a Michigan Technological University colleague, characterizes this flow as highly nonlinear and slightly dissipative. The theory gives encouraging predictions of the width of the zone and the speed of the currents within it.

Dr. Young has also focused on the role of western boundary layers in mixing both active and passive tracers. Because of the confluence in the entry region of the boundary layers, fluid parcels with very different material properties are juxtaposed and mix. Subsequently, when the fluid leaves the boundary layer, this mixing is amplified. This process can accelerate the dispersal of geochemicals in ocean gyres. Detailed theoretical analysis provides precise estimates of the time scales involved. These results have recently been confirmed by numerical calculations.

Dr. Robert Pinkel's group is developing a special-purpose Doppler sonar system, which when mounted on FLIP will measure the mean velocity profiles of the upper oceanic wavefield. Frequency spectra, wavenumber spectra, and combined wavenumber-frequency spectra can also be estimated from the sonar data. Graduate students are statistically analyzing data collected during a May 1980 cruise, approximately 300 km off the California coast. The spectrum is plotted into halves, with one corresponding to upward-propagating energy, the other to downward-propagating energy. The spectrum is dominated by a series of ridges paralleling the wavenumber axis at several frequencies. The lowest frequency ridge corresponds to near-inertial motion. A broad band of near-inertial wavenumbers is energetic. High-frequency ridges correspond to the baroclinic tide and what might be harmonics of the tide at inertial frequencies. These possible harmonics stand out at low wavenumber, but not at high, which indicates a steeper spectral slope (in wavenumber) for these ridges than for the regions between the ridges. The vertical coherence of the wavefield, which is related to the wavenumber bandwidth of the spectrum, should be correspondingly greater for the ridges than between them.

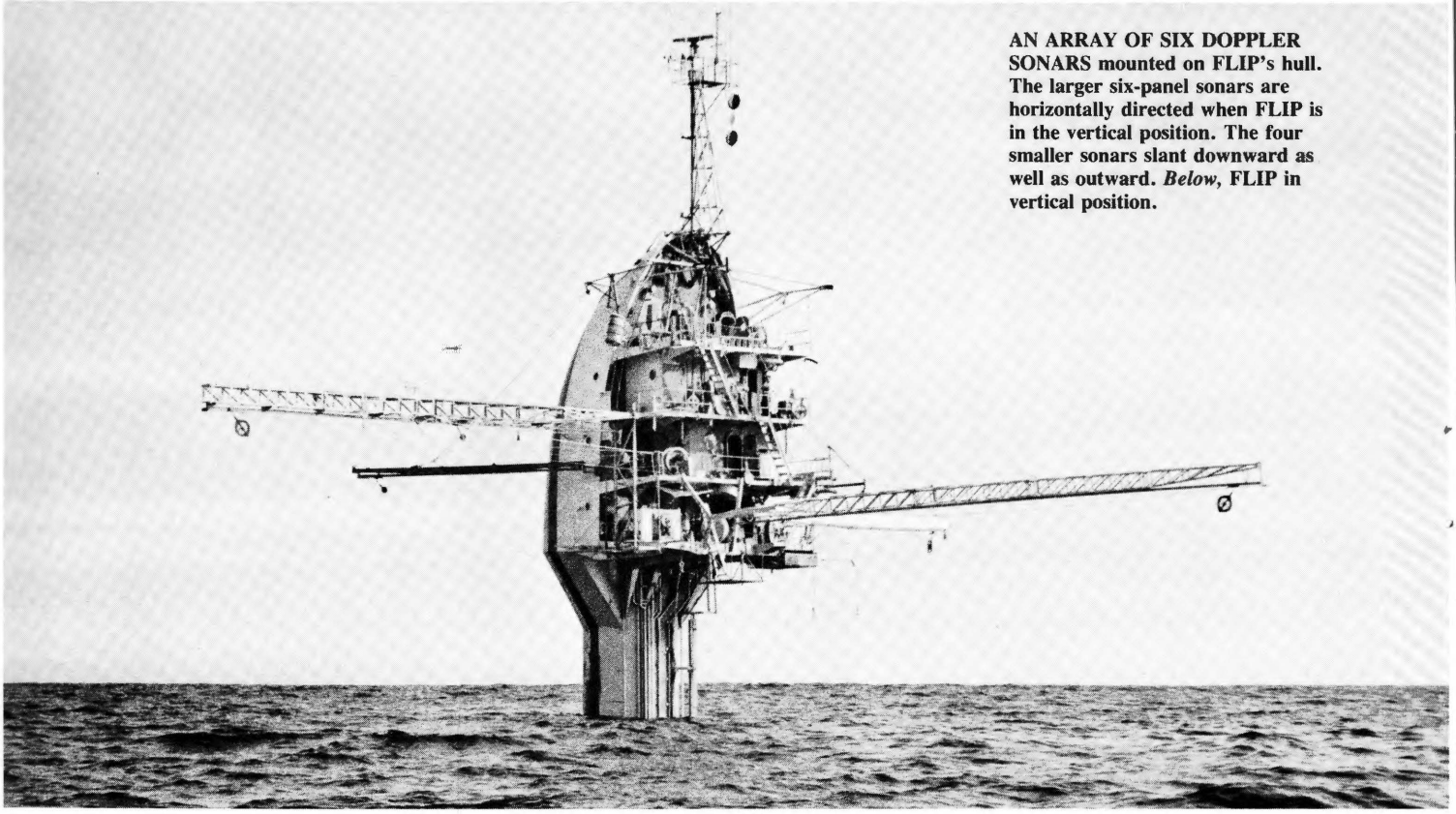
With the resolution of the internal wave spectrum, emphasis is shifting to observing changes in the spectral form with changing oceanographic conditions. Is the high wavenumber cutoff always present? Does its position change with changing wavefield energy? MPL engineers are developing a high-resolution Doppler sonar system that will allow a detailed look at the cutoff.

Dr. Frederick H. Fisher's group is investigating acoustic propagation in the ocean. Dr. R. Bruce Williams is leading the effort to design and build a 64-element, digital vertical array to be deployed from FLIP. The unique feature of the array is integration of 67-mm cable and the hydrophone for studies in the 100-400-Hz frequency range. Dr. Williams is also developing inexpensive self-recording temperature sensors. These sensors will be used to measure the long wavelength horizontal structure of the ocean's vertical temperature profile during acoustic propagation runs.

Another MPL research topic was the physical chemistry of seawater. Laboratory measurement of the effect of pressure on sound absorption in 0°C seawater was completed by Dr. Cheng C. Hsu and Dr. Fisher. Dr. Andrew G. Dickson is analyzing the results of these experiments and earlier sound absorption data with respect to ion-pairing models for seawater. He is also setting up a new laboratory for electrolyte emf studies. Drs. Dickson and Fisher are working on ways to model the pressure dependence of ion-speciation in seawater.

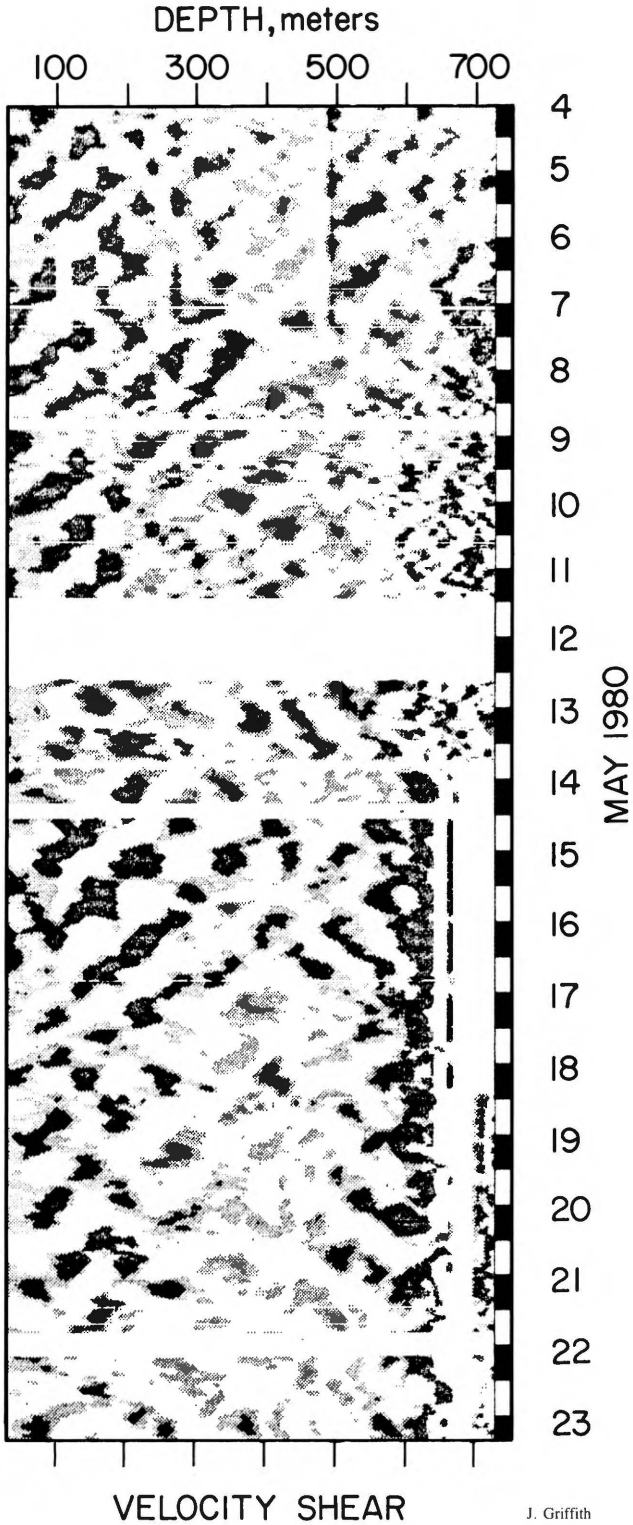
LLOYD L. GREEN, *foreground,* DR. ROBERT PINKEL, *center,* and MICHAEL GOLDIN run tests on a prototype Doppler sonar.

W. A. Call



L. M. Occhiello

AN ARRAY OF SIX DOPPLER SONARS mounted on FLIP's hull. The larger six-panel sonars are horizontally directed when FLIP is in the vertical position. The four smaller sonars slant downward as well as outward. *Below,* FLIP in vertical position.



A DEPTH-TIME PLOT of one component of shear as measured by a Doppler sonar. Dark areas correspond to regions of high shear. The stripelike pattern results from several near-inertial wave groups, which dominate the shear field during the observation period.

In collaboration with Dr. Victor C. Anderson's group, Dr. William S. Hodgkiss is designing and implementing the system control and quick-look/calibration-analysis software for a high-speed data recording system. As part of the ONR ACSAS program, the system will be used in studies of flow noise. In another joint project, work continues on the Swallow Float Program. The goal of this effort is to fabricate and take to sea a freely drifting array for measuring infrasonic acoustic ocean noise in the 1-10-Hz frequency region. Four of the buoys were tested successfully.

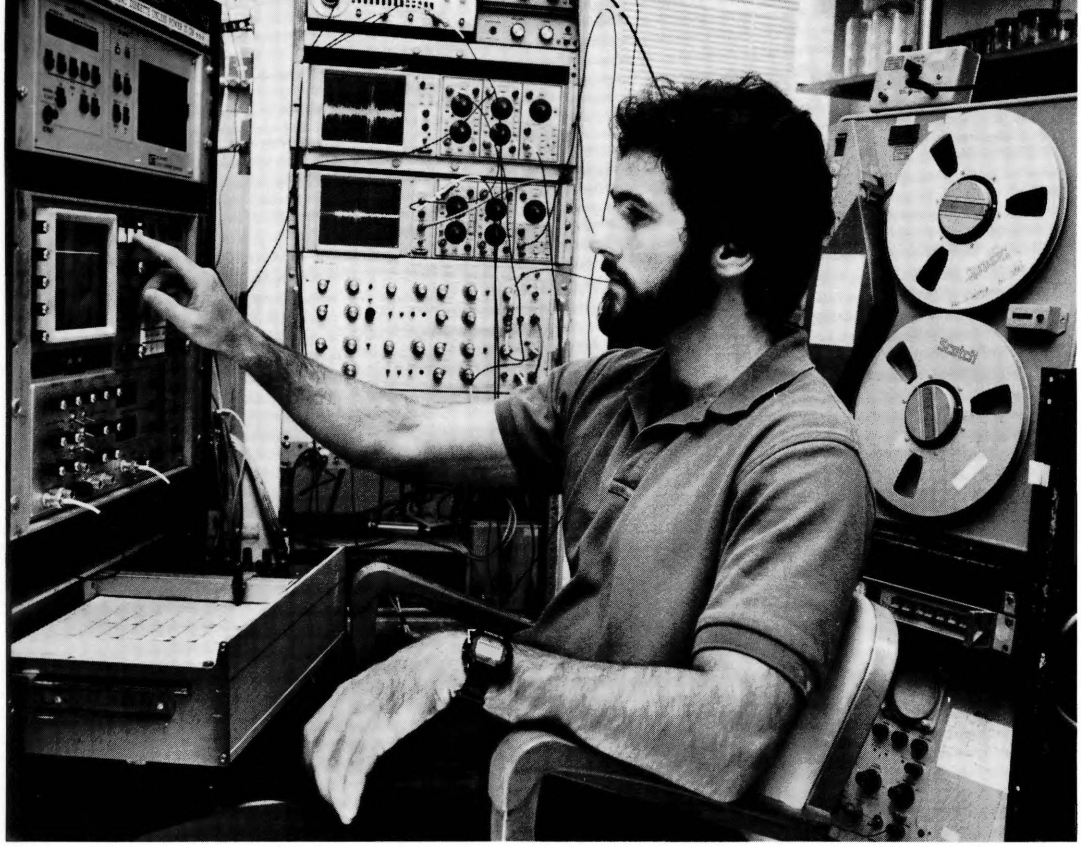
Dr. D. Scott Hansen completed his research on the application of autoregressive time-series models to the Doppler sonar problem. Graduate student Dimitri Alexandrou is investigating the capability of adaptive array processors to cancel (null) the surface reverberation return from an active sonar.

The investigation of the fine-scale nature of the seafloor highlighted a variety of research this year for Dr. Fred N. Spiess's group. Work centered on three expeditions, development of new and improved techniques for near-bottom surveys and marine geodesy, and data reduction and reporting for previous expeditions. Topics of principal interest were rise-crest phenomena, manganese nodule areas, acoustic backscattering, and young seamounts.

Dr. John A. Hildebrand is analyzing magnetic anomalies that indicate the direction of magnetization of seamount rock. Recent studies of both ocean-surface and ocean-bottom magnetic measurements show the complexity of the magnetization within seamounts and the inability of uniform models to accurately fit the measurements. A new approach to this problem calculates nonuniform internal distributions of magnetization, which may lead to greater understanding of seamount internal structure.

Dr. Peter F. Lonsdale is studying volcanic seamounts, using surface-ship surveying with Sea Beam, the MPL Deep Tow system, and research submersibles. Sea Beam bathymetric surveys, with concurrent collection of magnetic and gravity data, have continued to characterize the morphology and internal structure of several types of deep-sea volcanoes. Deep tow surveys in August 1983 yielded high-resolution information on the shallow structure of some of the volcanoes, especially those with deep summit craters. The variation in age and composition within individual cones was explored.

Dr. Victor C. Anderson's group continued developing the research vehicle RUM III, which will provide a remote manipulation capability on the deep seafloor. The vehicle will operate at the end of 10,000 m of coaxial strain cable to a depth of 5000 m. The lightweight (plastic) slow-speed thruster, which has variable pitch and torque capability, is completed. This component will position the vehicle above the seafloor. Also fabricated was the articulated boom, to be operated hydraulically with saltwater. The boom is made of lightweight fiberglass pipe and other plastics, along with a few high-strength metal parts for the high-stress portion. The control computer system has also been assembled, based on the 68000-type microprocessors.



GRADUATE STUDENT JEFF SCHWEITZER counts neuron firings per stimulus in a thornback ray. Top center screen shows ray's response to stimulus in water; bottom center screen is the ray's ongoing brain activity. Through this research Schweitzer is characterizing the ray's neurophysiology.

Neurobiology Unit

The Neurobiology Unit is associated with Marine Biology and the Marine Biomedical Program. The unit emphasizes neuroethological studies—the sensory and neural mechanisms of natural behavior of sharks, rays, bony fishes, marine mammals, and other taxa.

Dr. Theodore H. Bullock and several European and U.S. investigators are using comparative neurology to identify functional and structural brain differences that might be relevant to behavioral differences between taxa, one of the prime achievements of evolution. In one project the researchers are comparing different classes of vertebrates from fish to mammals—in respect to mathematical descriptors of the electrical activity of nerve cell populations, both in response to impinging stimuli and in the background, ongoing state. An array of semimicroelectrodes is implanted in the brain, and electroencephalographic recordings are analyzed for patterns in space and time.

Dr. Stephen M. Echteler, working on the hearing centers in carp, located auditory regions of the hindbrain, midbrain, tweenbrain, and two small parts of the cerebrum that are specialized for receiving and processing auditory input. One region is in an area thought to be equivalent to our basal ganglia, the other in a forerunner of the cortex. The dynamic properties of single as well as groups of nerve cells differ from those of the midbrain. This increases the evidence for differentiation of the telencephalon and distinct, parallel pathways for different sensory modalities—all the way to the forebrain—as a general feature of even the more primitive vertebrates. Dr. Echteler also found evidence of a systematic segregation of nerve cells that prefer different sound frequencies, forming an orderly map of frequency in the midbrain.

Drs. Luke T. Lee and Bullock defined some of the physiological properties of the output cells of the cerebellar cortex in catfish. These properties include the segregation of responsiveness to visual, tactile, acoustic, electrical, water-movement, and angular acceleration input. Forebrain input is also widely effective, but climbing fiber excitation is curiously confined. Dr. Eberhard W. Fiebig, using skates and other rays, succeeded in recording from the tiny granule cells that receive most of the cerebellar input, and found a second electroreceptive area. Graduate student Jeff Schweitzer and Dr. David Lowe anatomically worked out the pathways for electroreception in rays, up through the midbrain, and Schweitzer physiologically characterized them.

Ocean Research Division

Ocean Research Division (ORD) scientists work in a number of scientific disciplines, including marine biology, marine chemistry, marine physics, marine climatology, and physical oceanography. Rather than reviewing all scientific programs within ORD, this section highlights aspects of research in each of the five disciplines. Activities of the Physical and Chemical Oceanographic Data Facility, under the combined leadership of David Wirth and Robert T. Williams, are also covered.

A significant event for ORD is the completion of the new Physical Oceanography and Space Science building where, for the first time, most physical oceanographers and climatologists will be housed under one roof.

Climate Research

Members of the Climate Research Group, headed by Dr. Richard C. J. Somerville, focus on the Experimental Climate Forecast Center (ECFC), an effort funded by the National Climate Program Office (NCPO). Since 1981, when Drs. Tim P. Barnett, Jerome Namias, and Somerville and their colleagues were named the first ECFC, the group has produced and verified a series of experimental seasonal forecasts that are routinely submitted to the NCPO. Recently an independent national panel of experts appointed by the National Oceanic and Atmospheric Administration reviewed ECFC's work and gave strong approval. Some concepts relating to boundary influences and synoptics, developed by Dr. Namias and Daniel R. Cayan, are frequently used by the National Weather Service (NWS). An automated climate forecast system developed by Dr. Barnett and a colleague is now being incorporated into the NWS operational forecast scheme.

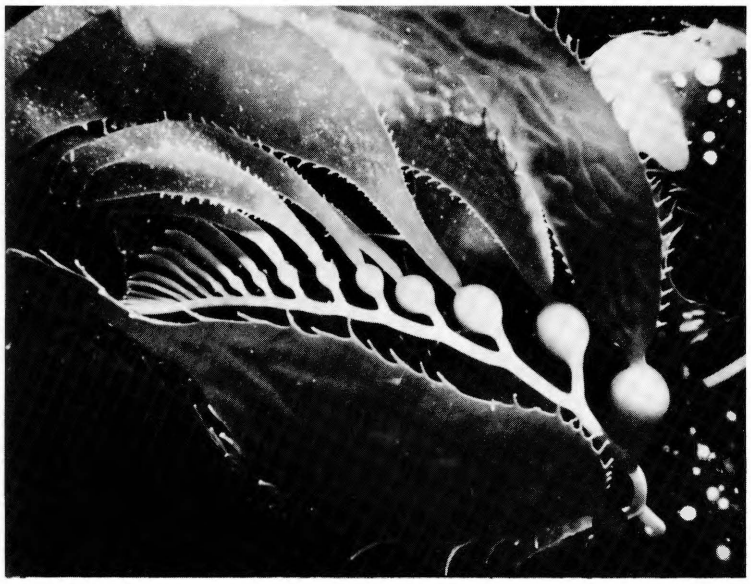
In other work, Dr. Barnett investigated global climate variations and was able to identify a possible precursor for El Niño, Southern Oscillation, and monsoon events as a propagating component in the sea-level pressure field that first appears over the Asian continent. The generation of this "wave" involves interactions between the Indonesian convergence system and the Siberian High. Additional investigations suggest this propagating feature may have long-lead predictability associated with it, which may allow seasonal predictions of up to a year.

Dr. John D. Horel and a Peruvian scientist are studying the oceanographic and meteorological conditions along the coast of Peru and the subsequent midlatitude and tropical interactions during the 1982–1983 El Niño. Dr. Horel is analyzing the Northern Hemisphere atmospheric circulation in order to document persistent states. A University of Maryland visiting scientist and Dr. Horel estimated the thermal inertia of the upper ocean, and are simulating the observed seasonal cycle of the surface wind field in the tropics.

Dr. Namias and Cayan proceeded with research in forecasting winter from the preceding summer and vice versa. They explored the roles of migrating ocean-temperature anomalies, persistence of atmospheric and oceanic variables, and climatological contingenices. As of now, only seven forecasts have been verified, but the results have been encouraging. Only one of the seven predictions (winter 1982) was inadequate, perhaps because of an unanticipated El Niño. Other research involved effects of snow cover, long-term temperature trends, strong subtropical wind systems, and recurrent North Pacific atmospheric blocking.

Drs. John O. Roads and Barnett studied spectral error characteristics of statistical forecasts for 1-to-32-day lead times for various predictor and predictand averaging times. In collaboration with Dr. Somerville, they compared these models with forecasts by global general-circulation models. Dr. Roads has been concerned with the error characteristics in two-level quasi-geostrophic models and, in collaboration with Dr. Warren B. White, with developing simple ocean models.

Dr. Somerville investigated the role of a cloud-feedback mechanism in the carbon dioxide climate problem. He found that as the climate warms because of increased CO_2, the clouds tend to contain more water and therefore to reflect incoming sunlight more efficiently. This decreases the warming caused by the CO_2. Dr. David H. Hathaway, National Solar Observatory, and Dr. Somerville investigated convection's role in maintaining the large-scale circulation of Jupiter. They found that on a rapidly rotating planet the jetlike winds can distort the structure of convection cells and thus feed momentum into the large-scale planetary wind field.



E. Hanauer

E. Hanauer

AFTER A COLLECTING TRIP, Dr. Mia J. Tegner measures a *Macrocystis pyrifera* holdfast with abnormal morphology probably caused by warm water. *Below left,* a specimen of healthy kelp; *right,* fronds of *M pyrifera* that have deteriorated as a result of nutrient stress during the 1984 El Niño.

Drs. Geoffrey K. Vallis and Roads studied linear and turbulent flow over topography in order to analyze the effect that synoptic-scale transient eddies have on stationary solutions. They found that these eddies have a strong damping effect. Dr. Vallis has also developed efficient and alias-free spectral numerical algorithms for channel models and is currently studying stochastic effects of eddies on large-scale flow.

Marine Biology: El Niño's Effect on Kelp Forests

A series of massive winter storms and the largest midlatitude El Niño ever measured devastated southern California kelp forests in 1983. Drs. Paul K. Dayton and Mia J. Tegner documented and differentiated the effects of these two major disturbances on this economically important resource.

The primary effect of the powerful storms was on giant kelp, *Macrocystis pyrifera,* the competitive dominant plant in this community. A San Diego-based kelp harvester reported that the surface canopy of *Macrocystis* in the Point Loma kelp forest decreased from 600 hectares in the fall of 1982 to fewer than 40 hectares after the winter storms of 1983. Diving surveys indicated two major types of storm damage to *Macrocystis:* (1) holdfasts were ripped off the substrate by large swells, creating large areas of open space; and (2) entanglement of attached plants with drifting plants and holdfast bundles caused extensive-to-complete loss of stipes. In contrast to the giant kelp, other kelp species, which stand only a few cm to 2 m above the substrate, suffered little or no damage from the storms.

The 1982-1983 El Niño was associated with warm sea temperatures, a deep mixed layer, and negligible nutrients. A strong negative correlation between temperature and nutrient concentrations has been established for the Southern California Bight; the concentration of nitrate, a critical nutrient for plant growth, is negligible at temperatures of 16°C and above. The El Niño may well have exerted an effect during the winter storms when the temperature averaged 16°C and only limited nutrients would have been available to the plants for repair of mechanical damage. There were indications of weak upwelling during the spring of 1983—when bottom temperatures dropped—but none during the summer. Bottom temperatures were above 16°C from August through October and soared as high as 21.4°C. The normal thermocline was depressed to depths below the kelp forest.

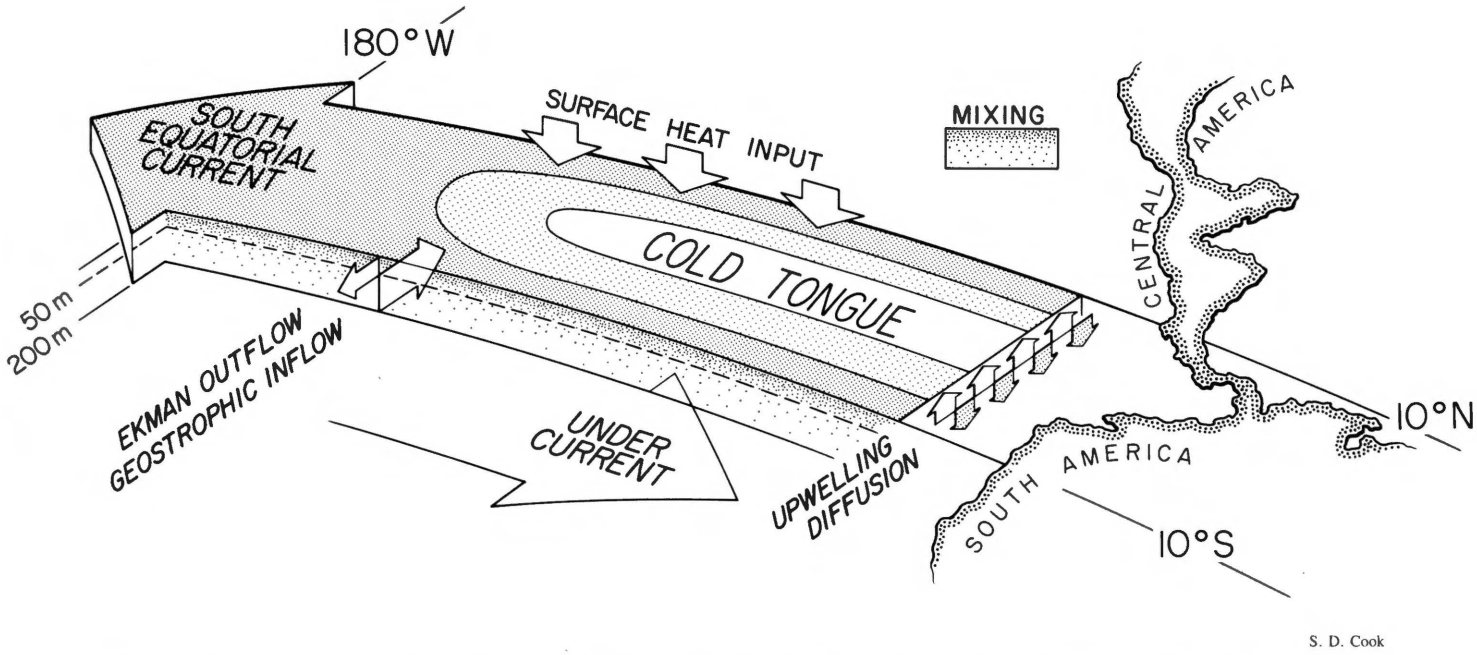
The results of the warm water on *Macrocystis* were dramatic. There was heavy mortality of adult plants that had survived the storms. By late summer, few plants had healthy upper fronds, and most plants had lost all their fronds. There had been a massive recruitment of *Macrocystis* after the storms, but the young plants fared poorly: by September the tops of many had died 2 m to 3 m above the bottom. For example, recruitment was first observed at one site in April, but by September the mean plant size was only 137 cm—poor for a species that can grow as much as 5 to 15 cm/day under optimal conditions. In contrast, many understory species of algae successfully recruited into areas once occupied by *Macrocystis.*

Water temperatures dropped in November, and conditions once again became suitable for growth and reproduction of surviving *Macrocystis.* The winter of 1984 was very mild, so storm mortality was negligible. Some of the algal species that recruited the previous spring were annuals, which died back during the winter, opening up space for additional *Macrocystis* recruitment. However, many of the understory species that recruited were perennials with considerable resistance to invasion by *Macrocystis;* in these areas community structure may be altered for years to come.

Marine Chemistry: Hydrothermal Activity in the Guaymas Basin

Researchers in Dr. Joris M. Gieskes's laboratory are studying hydrothermal activity's effect on the sediments and the water column in a young ocean basin. A collaborative effort with other Scripps groups is focused on the Guaymas Basin in the Gulf of California. This basin is of particular interest because new oceanic crust is generated beneath a thick blanket of sediments. Basaltic magma is intruded into this material as sills rather than being extruded on the seafloor, as occurs at midocean-ridge spreading centers. This intrusion profoundly affects the chemistry of the sediments and pore fluids. Hydrothermal fluids, which carry a strong chemical signal caused by thermal interaction with basaltic and sedimentary materials, exit the sediments along faults in the seafloor at temperatures ranging from 50°-325°C. The rising plumes of warmer waters subsequently form clouds of suspended material in the water column.

Studies this year have concentrated around water-column samples collected by graduate student Andrew C. Campbell. Attention centered on anomalies caused by the hydrothermal injections, not only in the chemistry of the dissolved constituents, but also of the particulate phases. Anomalies in temperature and dissolved constituents become easily noticeable below the sill depth of the Guaymas Basin (~1550 m), especially because of the relatively constant temperatures and salinities below ~1700 m. Hydrographic data in the immediate vicinity of a hydrothermal vent showed a drop in light transmission associated with increased cloudiness. This is mainly caused by precipitating manganese, which stems from hydrothermal injections. This precipitation was confirmed for the station very close to the vent field. Associated with this is a well-defined anomaly in dissolved silica, which in turn correlates with a magmatically derived anomaly in dissolved ^{3}He. Studies of sediments obtained in this area are in progress, and a return trip with a submersible will be made.



SCHEMATIC DIAGRAM showing the tropical Pacific upper-ocean currents and the physical processes that tend to change the temperature of the cold ocean tongue.

Marine Physics

Studies in Dr. Jean H. Filloux's laboratory are centered around acquisition and interpretation of long-term, open-ocean observations of electromagnetic (EM) variations and pressure fluctuations on the seafloor. EM variations provide direct information on the electrical conductivity structure of the oceanic mantle. This structure, in turn, imposes constraints on composition, liquid-vs-solid fraction, and lattice parameters. Following such seafloor magnetotelluric (SFMT) experiments over the northeastern portion of the Pacific plate, scientists proceeded westward to areas with older plates or with greater tectonic complexity, such as subduction zones and back arcs. In association with foreign institutions, the researchers launched an electric field recorder in the Tasman Sea from the Royal Australian Navy R/V HMAS *Cook*. In this study of the continent-to-ocean transition, an array of 21 seafloor and 8 land instruments operated for 100 days across southern Australia and the Tasman Sea.

For more than a century oceanographers have postulated the existence over the Northeast Pacific of an amphidrome—or point of zero tidal elevation—for the semidiurnal tide. Past attempts to predict its location have been many and have resulted in widely spread tentative locations. A series of 10 seafloor pressure data, collected during SFMT experiments mentioned earlier, provided a detailed image of tidal fluctuations in an area sufficiently close to the actual amphidrome to define its position within less than one degree (for lunar constituent M2).

Physical Oceanography: Tropic Heat

Scientists involved in the multi-institutional program Tropic Heat are studying the physical processes that determine upper-ocean distributions of temperature and velocity in the central and eastern equatorial Pacific Ocean. In this region there is a long tongue of relatively cool sea-surface temperature (SST) straddling the equator from South America to the dateline; it is one of the most conspicuous features of the global SST pattern. SST values in the center of the tongue can be as much as 7°C colder than those a few hundred km north or south. The intensity of the tongue changes in an annual cycle: strongest in Northern Hemisphere spring, weakest in autumn. Tropic Heat study should result in better quantitative estimates of the principal mechanisms of heating and cooling, which determine the SST pattern and its annual evolution in this region. The list of possible processes is complex. Tropic Heat study will not yield a fully closed budget of all these heat fluxes, but it should improve understanding of the major ones, and of their variations in space and time over an annual cycle.

Apart from purely scientific curiosity about the workings of this enormous tropical ocean heat machine, why should one care? An answer lies in the importance of this region and of its SST distribution to large-scale departures from normal atmospheric and oceanic conditions: climatic fluctuations. Computer simulations of atmospheric dynamics implicate the tropical Pacific as a key region in which perturbations of normal ocean-atmosphere interactions, and

particularly of the evaporative heat flux (which is a stong function of SST), can cause significant and sustained aberrations in atmospheric circulation. The 1982-1983 El Niño episode, which was the most intense of its kind ever satisfactorily documented, serves as a recent reminder of the effects that such climate fluctuations can have on human affairs. The list by now is familiar: record drought in Australia; record rainfall and flooding in coastal Peru and Ecuador; abnormally high sea level, severe storms, and coastal property damage in California. A rough estimate of worldwide economic losses attributed to this El Niño is $8.6 billion.

Tropic Heat field work is now in progress, with National Science Foundation support. Dr. P. Peter Niiler, executive committee head, worked on developing satellite-tracked drifting buoys to measure upper-ocean thermal structure and air-sea interaction parameters such as air temperature SST, and relative humidity. Other drifting buoys, used to mark ocean currents, have been placed into the cold tongue by Gerard J. McNally. Drs. Russ E. Davis, Robert A. Knox, Douglas S. Luther, and Dean H. Roemmich are deploying arrays of near-equatorial current-meter moorings to make long time series measurements of velocity and temperature at several upper-ocean depths. The surface buoys of these moorings also serve as platforms for further wind and air-sea interaction measurements conducted by Dr. Niiler and a Woods Hole Oceanographic Institution colleague.

Dr. Catherine Gautier is using satellite data to test the feasibility and accuracy of deriving such essential fields as atmospheric temperature and humidity profiles to calculate the evaporative heat flux. Dr. Lloyd A. Regier, in collaboration with colleagues from other institutions, is taking part in an intensive ship survey of near-equatorial small-scale ocean mixing processes. Dr. Regier's contribution will be detailed, finely resolved measurements (using a Doppler acoustic log) of the upper-ocean velocity profile.

Physical and Chemical Oceanographic Data Facility

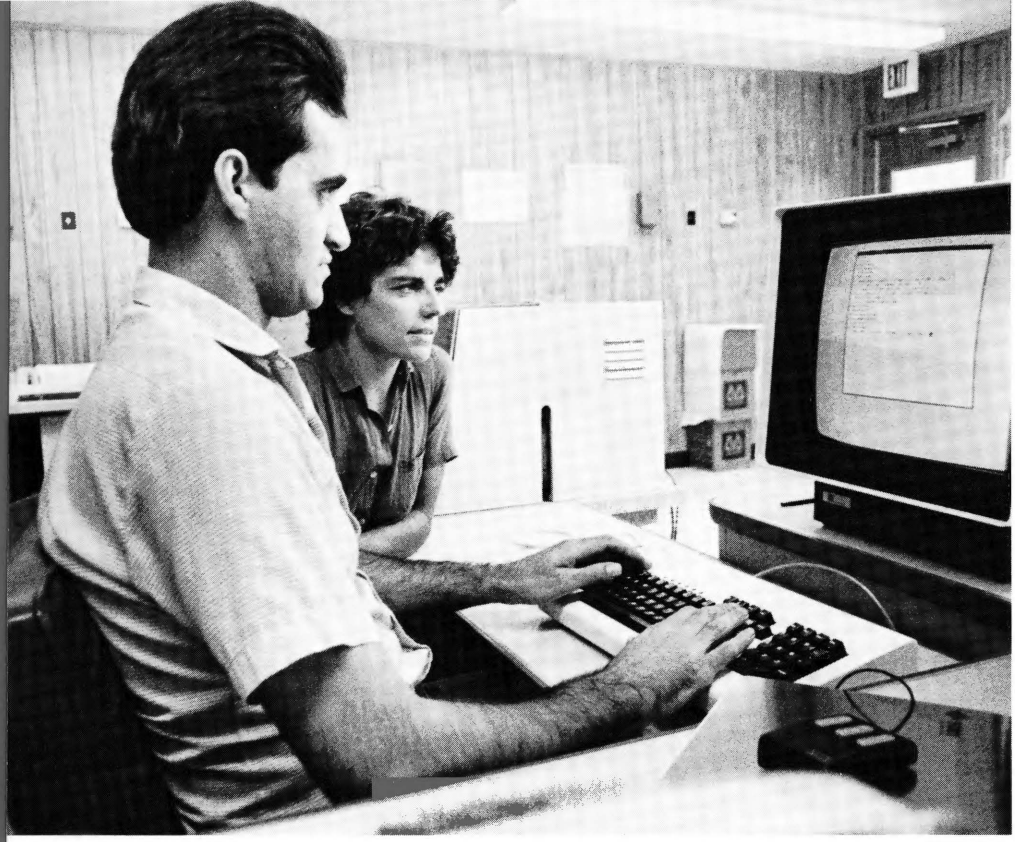
The Physical and Chemical Oceanographic Data Facility (PACODF) has supported local Scripps surveys of the California Current system as well as distant investigations in the Arctic Ocean and the waters surrounding Antarctica.

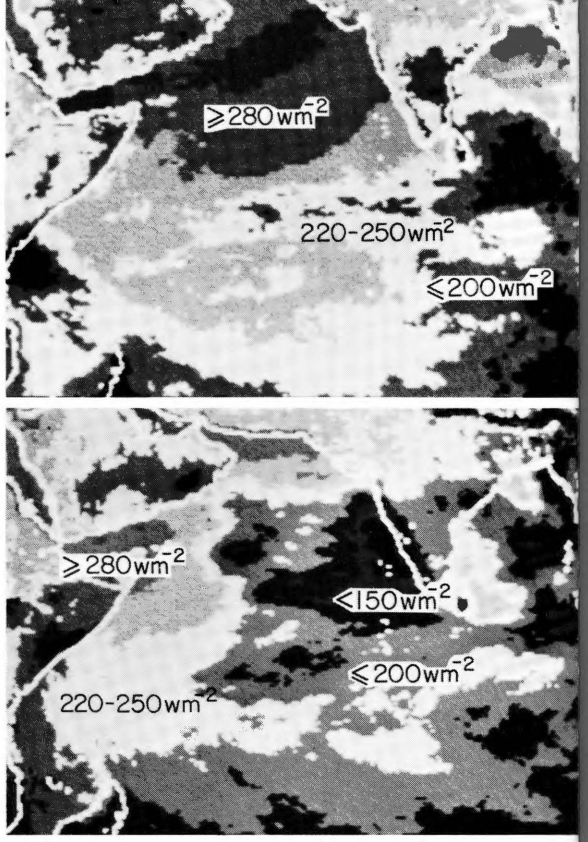
A major expedition in the South Atlantic was initiated by Joseph L. Reid and a colleague to provide high-precision hydrographic data of an area where only sparse measurements were previously available. PACODF provided much of the technical support for the expedition, measuring salinity, dissolved oxygen, and nutrients, as well as taking samples and processing data. Data were taken along 0° longitude southward until progress of the ship, R/V *Knorr,* was stopped by the permanent ice field.

PACODF provided shipboard chemistry, particularly nutrient measurements, to the California Cooperative Oceanic Fisheries Investigations (CalCOFI) program, which conducted a major series of expeditions in the California Current system in 1984 to investigate the environment and general biology of pelagic fish and other organisms of the eastern North Pacific Ocean.

PACODF staff worked with Dr. James H. Swift on an international program to investigate the hydrography of the Greenland-Spitzbergen Passage (Fram Strait) as well as the Arctic Ocean. Prior to this expedition (aboard the German polar research vessel *Polarstern*), no high-quality hydrographic data existed from the Eurasian sector of the Arctic Ocean or the Northeast Greenland slope and shelf. This data set should contribute significantly to the understanding of thermohaline circulation and exchange in the region.

PACODF continues to advance the state of high-precision hydrographic data by upgrading both data acquisition and processing equipment used aboard ship, and by installing a calibration facility. This facility will, when completed, provide high-precision determinations of pressure, temperature, and conductivity throughout all the ranges found in the ocean.





Cal Space

Left, **SERGE C. MASSE AND DR. CATHERINE H. GAUTIER processing GOES satellite data on their image display system in preparation to making radiation computations.** ***Right,*** **black-and-white reproductions of color-coded images. At** ***upper right*** **is map of net solar radiation at the surface (averaged over two weeks in May). It shows large heat input ($\geqslant 280 wm^{-2}$) in the Arabian Sea, before the onset of the monsoon season. The map at** ***lower right*** **shows the same area after the monsoon has started (two-week average in late June). Low values of radiation ($< 150 wm^{-2}$) correspond to intense convection/precipitation.**

California Space Institute

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

Cal Space activities in climate research are directed toward two major problems: (1) the coupling between the ocean and the atmosphere, particularly at the interface, and (2) the interaction between clouds and radiation.

The large-scale air-sea interaction studies of Cal Space are within the framework of the international Tropical Ocean Global Atmosphere (TOGA) program. The particular interests of Cal Space are in the effect that the net solar radiation at the ocean surface has on the upper-ocean heat budget (in both the Pacific and the Indian oceans).

Cloud/radiation interaction studies at Cal Space address the importance of changes in marine boundary-layer stratus clouds on the upper ocean and climate. Cal Space researchers are exploring ways of determining the radiative and physical cloud parameters from satellite observations, and of monitoring their changes. Cal Space scientists are also involved in planning new satellite experiments, such as the proposed Franco-American Satellite Experiment TOPEX-POSEIDON.

Cal Space scientists are beginning a one-year study of the role that automation technology and robotics will take in space-station activities. This study will facilitate decisions to ensure a flexible and growing capability for activities in near-earth space. Research in the use of lunar materials in space is continuing. Oxygen and metals from lunar soil are early targets for this laboratory-scale program.

The first planetary mission in the new low-cost mode (the Mars Geoscience/Climatology Observer) has been authorized by the U.S. Congress. This satellite will carry a gamma-ray instrument that was built by Cal Space scientists to map the concentration of major and radioactive elements on the Martian surface. Data analyses will be carried out by Cal Space scientists and their collaborators. Plans for missions to other planets call for the same or similar instruments.

Institute of Geophysics and Planetary Physics

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

Dr. George E. Backus continues to use the great magnetic jerk of 1969 in estimating the electrical conductivity of the lower mantle, motions in the fluid core, and the electromagnetic coupling of core and mantle to alter the length of the day. He also devised a formalism for dealing with and codifying the observed effects of magnetospheric currents on the Gauss coefficients produced by Magsat. He described all possible crustal magnetizations that produce no external geomagnetic field.

Dr. Duncan C. Agnew is studying ocean tidal loading and sea-level changes in the Aleutians. He studied methods for the continuous measurement of tilt and strain, and developed a procedure for comparing these methods with geodetic techniques.

The Cecil and Ida Green Piñon Flat Observatory, a field station for long-term measurements of crustal deformations in a region near the major San Andreas and San Jacinto faults, continues to grow under the direction of Frank K. Wyatt, with assistance from Dr. Agnew. At present, 20 institutions are operating more than 35 instruments at the observatory. A three-component, directional, deep borehole strainmeter was added this year by the University of Queensland. A second optical anchor on the northwest-southeast strainmeter was completed in December; subsequent data from this instrument show extremely small fluctuations. Three long-base tiltmeters were compared, and the hydrological effects of subsurface joints on deformation measurements were studied.

As part of a cooperative project with U.S. Geological Survey scientists, Dr. Jonathan Berger and graduate student Frank L. Vernon continue their seismic activity investigations of the Anza area on the San Jacinto fault. Data from a three-component, ten-station array is telemetered via VHF and microwave radio to IGPP, where events are detected and recorded on a computer system, which is being redesigned to make it portable and increase reliability.

Dr. Hugh Bradner continues to work with the multiuniversity project DUMAND (Deep Underwater Muon and Neutrino Detection). Project scientists plan to place a large array of 40-cm diameter photomultipliers on the ocean floor to study cosmic ray muons and the high-energy neutrinos that come from very hot stellar objects.

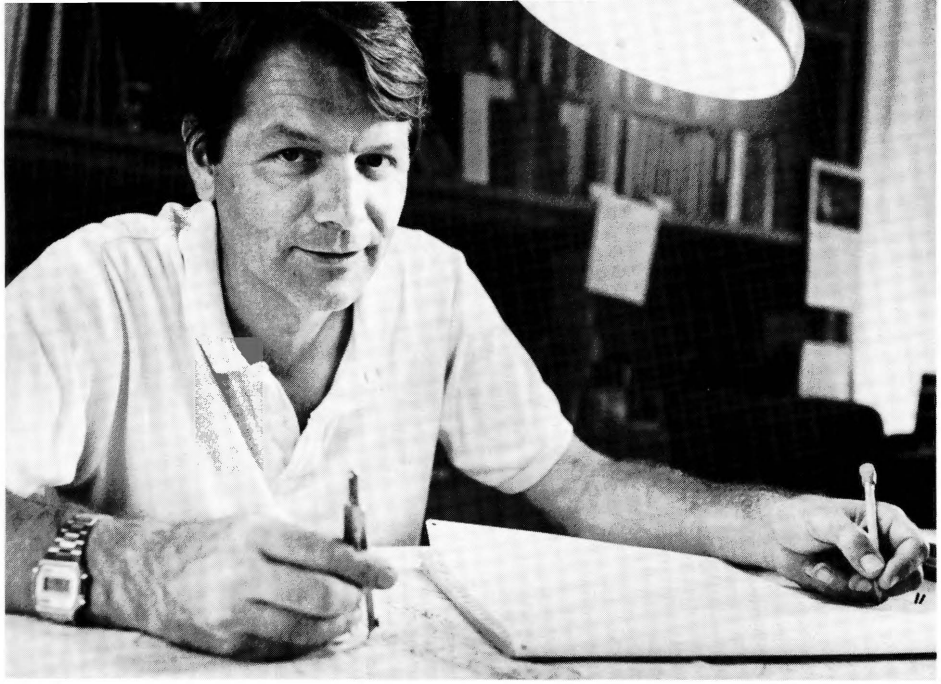
Drs. James N. Brune, John G. Anderson, and Michael S. Reichle continue cooperative seismic studies with Mexico. Their studies encompass seismic hazard, earthquake strong motion, earthquake mechanism, and earth structure. Observations and theoretical, numerical, and physical models were combined to clarify and estimate the probabilities of large ground accelerations that might damage structures like nuclear power plants.

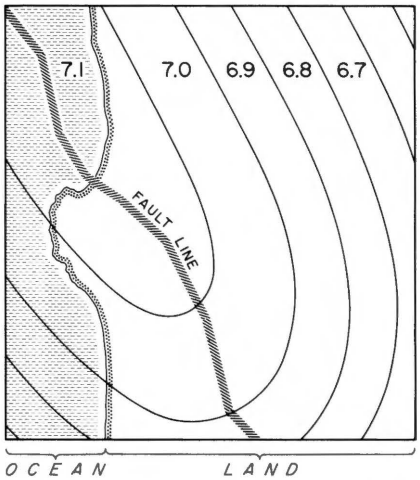
Drs. Anderson and Brune are directing the installation of a strong motion accelerograph array in the state of Guerrero, Mexico. The array consists of 29 digital recording accelerographs installed in the seismic gap that last ruptured in a four-earthquake sequence between 1899 and 1911.

Dr. Anderson and graduate student Susan E. Hough found that the shape of the Fourier amplitude spectrum of acceleration at high frequency follows an exponential shape, $e^{-\pi\kappa f}$. The decay parameter κ, which is related to attenuation of the seismic waves, increases systematically with epicentral distance from a finite value that is a characteristic of the site.

Dr. Anderson and a UC San Diego colleague studied the effect of the recording pier on records of strong earthquake ground motion. As part of a cooperative U.S.-Mexico study of crust and mantle structure along the cordillera of western North America, three long-period seismograph stations are being operated in Mexico by IGPP scientists and colleagues.

Dr. Reichle is working on a cooperative program to assess seismic hazards in the California/Baja California border region. Scientists will forecast seismic intensities of possible earthquakes along local fault zones and the damage that may result. Drs. Reichle and Brune are developing a binational earthquake emergency response and mitigation program for the Federal Emergency Management Agency and the State Office of Earthquake Services.





DR MICHAEL S. REICHLE quantifies seismic hazard. Map shows results of a model predicting Modified Mercalli Intensity for a hypothetical earthquake. Numbers indicate intensities forecasted for igneous rock. Local geological factors can raise intensities by up to two units.

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

Dr. John Miles continues work on chaotic motion in dynamical systems governed by sets of nonlinear differential equations.

Dr. John A. Orcutt and colleagues completed initial studies of the use of high-frequency seismic waveform data in large inverse problems, which iteratively solve for the elastic structure of the earth. Earlier they used qualitative abstractions of the data, such as travel times and amplitudes, to bound the variation of these elastic parameters. The new approach uses the richness of the entire seismic waveform in the constraint problem at the expense of requiring enormous computational resources. Several new approaches for dealing with the computational problem were developed, and a firm foundation was laid for future work on this inverse problem. Dr. Orcutt and a colleague completed an extensive evaluation of computational algorithms for the propagation of elastic waves through realistic spherical models. Such reliable programs are required for evaluating earth structure and source mechanism effects on the structure of seismograms recorded following an earthquake or (perhaps nuclear) explosion. Dr. Orcutt and graduate student Kevin R. MacKenzie studied seismic waves scattered from the crust-upper mantle transition or Mohorovičíc discontinuity to develop a detailed model of this structure in the seafloor. This model was successfully compared with geological studies of exposed ancient oceanic structures deposited on continents.

Drs. Orcutt and Olson developed additional new constraints on a seismic inverse problem involving travel times. Dr. Orcutt and graduate student Mark S. Burnett continued analyzing seismic data collected on the volcanic East Pacific Rise. The data support the existence of a shallow, perhaps permanent magma reservoir responsible for generating the bulk of the earth's crust.

Dr. Robert L. Parker continues to investigate linear and nonlinear inverse problems of geophysics. He and graduate student Giovanni B. Marchisio applied a variant of the Gel'fand-Levitan method (originally invented for quantum scattering theory) to the magnetotelluric inverse problem. A difficulty of earlier analytic techniques was the tendency to produce improbably oscillatory models; a regularization introduced in the new method successfully suppresses such behavior and allows the consistent construction of geophysically reasonable solutions.

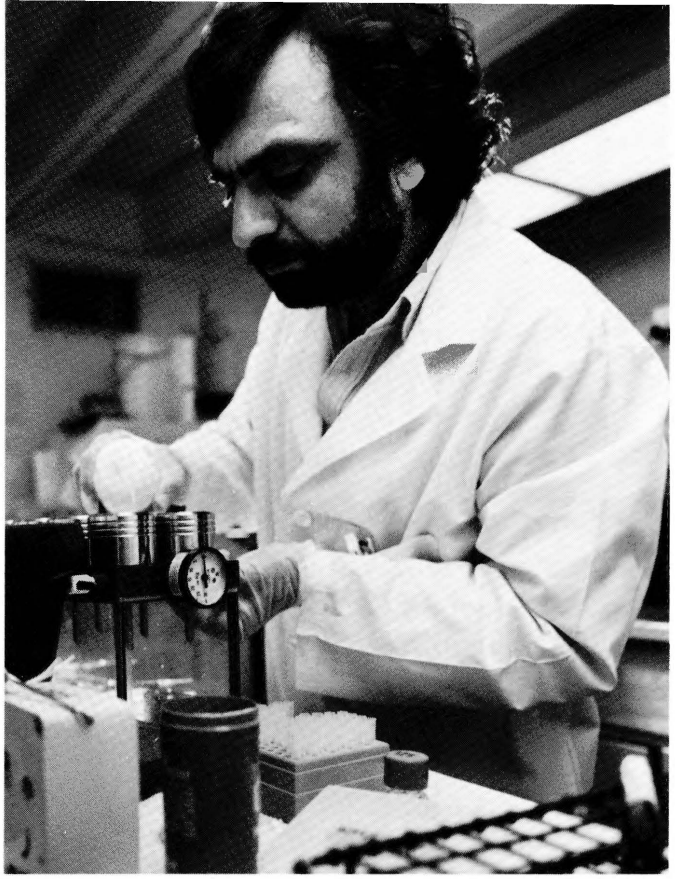
Dr. Robert H. Stewart continues as project scientist for TOPEX, a proposed new oceanographic satellite for measuring the surface geostrophic currents and waves of the oceans. With graduate student Jeffrey A. Nystuen, Dr. Stewart is studying the subsea noise made by rain. They find that rain is very noisy, but the spectrum of rain noise differs from that of wind noise, so it may be possible to monitor both in the open ocean with drifting buoys.

In a multi-institutional program, Drs. Peter F. Worcester, Walter H. Munk, Robert A. Knox, and Bruce D. Cornuelle continue their research in ocean acoustic tomography. (See highlight section Ocean Acoustic Tomography.)

Bernard D. Zetler continues his ocean-tide research. He completed a harmonic method of predicting tides by adding node constituents in place of annual approximations of amplitude factors and phase corrections currently used for the 18.6-year cycle in the longitude of the moon's node.

Institute of Marine Resources

The universitywide Institute of Marine Resources (IMR), directed by Dr. Fred N. Spiess, is headquartered at Scripps and supports a variety of research activities throughout the UC system. During the year IMR helped sponsor three conferences: a binational conference on U.S.-Mexican relations in the field of marine resources, a multicampus workshop on ocean engineering, and the Second International Symposium on Underwater Remotely Operated Vehicles (ROV'84). IMR also published a directory listing UC personnel with research expertise relevant to fisheries problems.



DR. FAROOQ AZAM filters seawater samples after incubating them with tritiated thymidine as part of a study to measure bacterial productivity.

Food Chain Research Group

Dr. Farooq Azam and his co-workers are studying the role of bacterioplankton in the flux of matter and energy in pelagic marine food webs. Dr. Azam spent six months at the International Atomic Energy Agency, Monaco, examining the importance of bacterioplankton in scavenging radionuclides from seawater; marine bacteria have not previously been emphasized in studies of radionuclide uptake. Dr. James W. Ammerman is exploring the importance of marine bdellovibrios, small predatory bacteria, as consumers of bacterioplankton. He has also focused on bacterial cell-surface enzymes that regenerate orthophosphate from organic phosphorous compounds on seawater. Graduate students are investigating periplasmic proteins of marine bacteria and clustering of natural bacterioplankton populations around nutrient sources in seawater.

Dr. John R. Beers is making quantitative studies of the feeding and reproduction of a nonloricate oligotrichous ciliate of the family Strombidiidae. The ciliate has been isolated from Southern California Bight waters and established in laboratory culture. Preliminary results, as evidenced by the ciliate's division rate and food intake, indicate that it responds similarly to highly concentrated food and to the more "average" abundances used in the experiments.

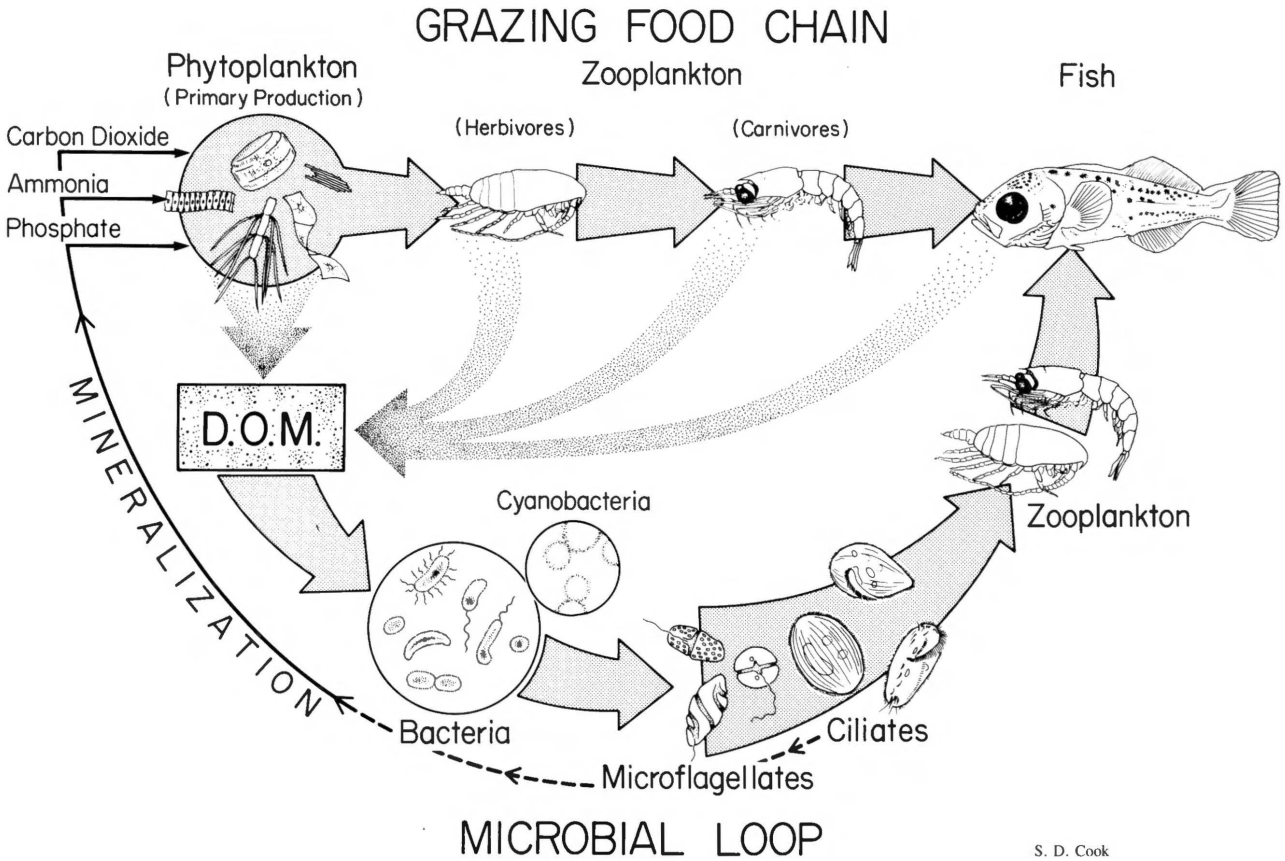
As part of the Food Chain Research Group project to determine the fate of biogenic organic materials produced in the surface waters of the Southern California Bight, Dr. Beers is studying the mass flux and the forms of sestonic materials sedimenting to the bottom in the Santa Monica/San Pedro Basin.

Dr. Angelo F. Carlucci studied the metabolism of amino acids by surface-film microorganisms while on a cruise to Baja California. Surface films contain unique and highly active microheterotrophic populations, which are not inhibited by solar radiation. Day-night studies of microheterotrophic metabolism of amino acids showed that activity is correlated with phytoplankton production.

Dr. Richard W. Eppley is assessing historical data sets of chlorophyll and primary production measured from ships. The rate of photosynthesis in the ocean depends on the chlorophyll content of the phytoplankton, thus satellite images of chlorophyll can be used to estimate rates of plankton productivity on a global scale. Results to date show large differences between regions of the ocean, as well as between seasons.

Dr. Osmund Holm-Hansen is studying organic carbon cycling by microbial cells in marine waters. He is concentrating on two aspects of this problem. (1) He is measuring the release of photosynthate, particularly amino acids, as a function of nutrient stress. (2) Together with other Food Chain scientists, he is determining the biomass and trophic mode of nanoplankton (<200 μm in size) and microplankton (<200 μm) in order to estimate the impact of grazing by microbial heterotrophs.

Dr. George A. Jackson is investigating interplay of biological and physical processes in a kelp bed in order to build a model of kelp currents. This model could then be used to study the spatial structure of ecological interactions. Dr. Jackson and colleagues are modeling the growth of the giant



THE "MICROBIAL LOOP." A significant part (⅓-½) of primary production is lost from the classical "grazing food chain" in the form of dissolved organic matter (DOM). The DOM pool is utilized almost exclusively by heterotrophic bacteria, and it supports significant bacterial secondary production. Bacteria are preyed upon by protozoa (microflagellates, ciliates), which in turn are eaten by crustacean zooplankon, thus linking the microbial loop with the grazing food chain. Photosynthetic bacteria (cyanobacteria) also enter the microbial loop when they are eaten by protozoa. Because several trophic transfers occur within the microbial loop, a large fraction of carbon, nitrogen, and phosphorus may be mineralized (converted to carbon dioxide, ammonia, and phosphate).

kelp, *Macrocystis pyrifera*. They hope to predict the effect that different environmental conditions and management strategies will have on growth and harvest of kelp beds. Working with FCRG scientists, Dr. Jackson is studying water exchange across the sills of the Santa Monica-San Pedro Basin off Los Angeles.

Dr. Michael M. Mullin's research emphasizes the effect of small-scale distributions of phytoplankton and zooplankton on the transfer of organic matter through the marine food web. He has analyzed the composition of nearshore zooplankton on transects from Dana Point to San Diego during the winters of 1983 and 1984 to determine the patterns during these El Niño periods. Graduate student Jeffrey M. Napp designed equipment to determine the feeding rates of zooplankton at particular depths without removing the animals from the environment. Napp uses radioisotopically labeled food to determine whether the animals feed more intensively at the depth where the biomass of phytoplankton is greatest or at the (usually shoaler) depth where the phytoplankton growth rate is maximal.

Dr. Bess B. Ward is investigating two steps in the ocean's nitrogen cycle: regeneration of nitrate via bacterial nitrification, and microbial assimilation of inorganic nitrogen. Environmental variables like light intensity and oxygen and substrate concentration influence the rates and distributions of these nitrogen transformations in the sea. Dr. Ward is using immunological techniques to study the diversity, distribution, and activity of several species of marine nitrifying bacteria.

Dr. Peter M. Williams's studies on the chemical composition, half-life, and formation rates of sea-surface films are near completion. A final cruise to the Guadalupe-Cedros Island area off Baja California was made with Mexican scientists. Studies on the cycling and budgets of organic matter in the Santa Monica-San Pedro Basin system continue. Amino acid and carbohydrate components of dissolved and particulate organic phases reflect the turnover of subsurface waters in the basin and microbial degradation and diagenesis of organic matter in the water column.

Marine Bio-Optics Group

The University of California Marine Bio-Optics Group (UCMBO) is an IMR intercampus group with operations at Scripps (coordinated by Karen S. Baker) and at UC Santa Barbara (directed by Dr. Raymond C. Smith). The group

continues to participate in multi-institutional research programs emphasizing theoretical and experimental marine bio-optics and remote sensing. Scientists in West Coast programs study phytoplankton dynamics in the eutrophic coastal waters off California, using data collected from 1979 to the present. Various data bases are being integrated to permit an approach to a system's view of the coastal area. Researchers in the East Coast warm core ring project are investigating the processes associated with rings that are anticyclonic mesoscale eddies that have separated from the Gulf Stream. The data from five cruises, from September 1981 to September 1982, are being analyzed to yield a seasonal view of the shelf, slope, and Sargasso Sea, as well as warm core rings.

Questions pertaining to multiplatform sampling strategies and order-of-magnitude increases in sampling rates have been addressed. Shipboard data from the bio-optical profiling system now give simultaneous optical, physical, and biological water column measurements. Remote sensing imagery, both color and temperature, is giving new insights into the coastal areas of the East and West on a variety of space and time scales. Preparations are complete for installing a new computer to augment the UCMBO image processing facility and to facilitate work with the data bases.

Marine Natural Products Group

Unique organic compounds produced by marine plants and animals are the focus of Marine Natural Products Group scientists. With the guidance of Dr. William H. Fenical, the group investigates the biologically active, often toxic, substances produced as chemical defenses by soft-bodied marine organisms. Dr. Amiram Groweiss is studying the natural products chemistry of Caribbean and Pacific sea whips (Gorgonian corals).

Ocean Engineering Research Group

The Ocean Engineering Research Group (OERG), directed by Dr. Richard J. Seymour, undertakes applied oceanographic studies in support of human intervention in nearshore and offshore waters. As part of the OERG's continuing study of wave climatology in the northeastern Pacific, Dr. Seymour is investigating the influence of El Niño Southern Oscillation (ENSO) events on extreme storm waves. He has found that the wave climate of central and southern California has been dominated by ENSO-related events since 1900.

David Castel and Dr. Seymour are developing a seawater pump driven by wave energy in shallow coastal waters, which may apply to reverse osmosis and to innovative harbor dredging techniques. David P. Bothman and Dr. Seymour investigated the use of cold seawater from moderate depths to extract fresh water from marine air. They found that the most promising scheme is to couple this system to a shore-based Ocean Thermal Energy Conversion (OTEC) plant and to use the cold water after it passes through the OTEC cycle. A 10 MW electric plant is capable of producing about 7.5 million liters per day of fresh water as a by-product. Christopher G. Gable and Dr. Seymour are studying the seasonal trends in sediment transport along a 100-km stretch of coastline, using the hydrostatic profiler developed by OERG.

Phytoplankton Resources Group

The Phytoplankton Resources Group, led by Dr. William H. Thomas, continues collecting, isolating, and culturing desert algae. Two field trips to the deserts of eastern California and western Nevada were made, and approximately 100 strains of desert saline algae are now in culture. Most of these grow well in artificial salt media at 20°-25°C and at the salinity of the waters from which they were isolated. They grow best at light intensities approaching 50%-60% of maximum La Jolla sunlight. Yields of one of these algae were as great as 70 gm m^{-1} day^{-1}. This would be 100 tons dry weight $acre^{-1}$ $year^{-1}$ if such yields could be achieved in outdoor pond cultures in the desert.

Polar Research Program

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

Dr. Holm-Hansen's group completed one project in Peard Bay (80 km southwest of Barrow, Alaska) and the Chukchi Sea, which is part of a major migratory route for many economically important marine mammals and birds. The Peard Bay food web is unusual because there is relatively little grazing by pelagic zooplankton, but carbon and nutrient cycling rates are high in the euphotic zone as a result of microzooplankton grazing. Researchers found that many benthic crustaceans ingest significant amounts of kelp-derived detritus.

The Polar Research Program was represented on two major Antarctic expeditions. One was concerned with food-web dynamics associated with a receding ice edge, and the other was a study of feeding, growth, and development of krill larvae under natural conditions. During this latter cruise on board R/V *Melville,* Dr. Mark E. Huntley and associates conducted the first extensive sampling and study of salp distribution, feeding, and physiology in polar waters. Phytoplankton studies, conducted by Christopher D. Hewes, showed the dominance of nanoplankton (less than 10 μm in size) in Antarctic waters. The abundance of microplankton (mostly large diatoms) is inversely related to the abundance of krill, as determined acoustically on this cruise.

California Sea Grant College Program

The California Sea Grant College Program is headquartered at Scripps and directed by Dr. James J. Sullivan. The Sea Grant program supports marine research, education, and advisory activities designed to accelerate the wise development of the nation's marine resources. This year, 56 projects in fisheries, aquaculture, coastal resources, new marine products, ocean technology, and marine affairs were conducted statewide. Of these projects, 12 were conducted at Scripps, including the cooperative international program with Mexican institutions.

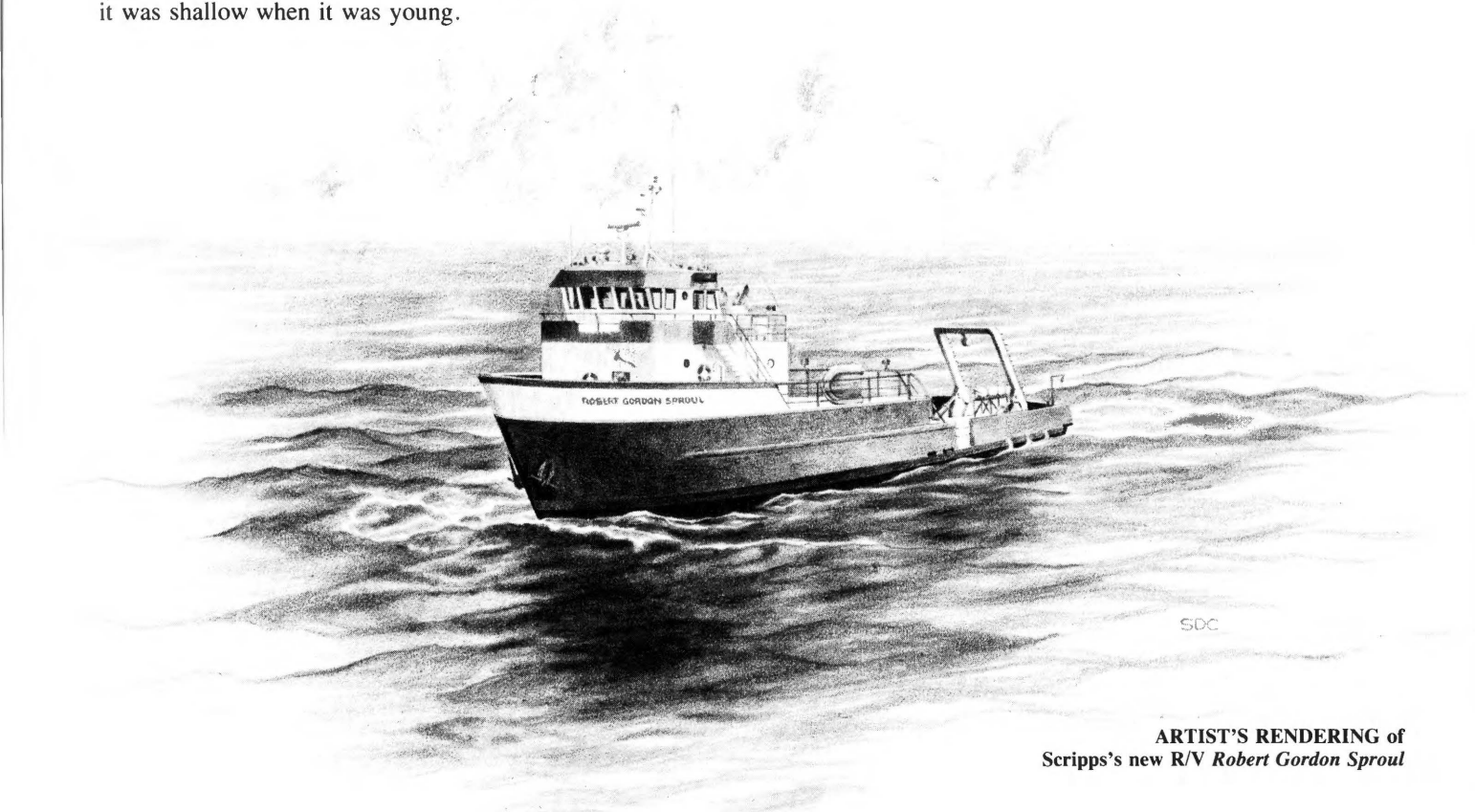
Other IMR Research Activities

The growth, distribution, and history of seamounts and oceanic islands is the focus of Dr. H. William Menard's research. Dr. Menard and colleagues noted that seamounts are far more abundant than originally thought and that the size distribution of seamounts is exponential. Dr. Menard found it highly probable that any given guyot is a drowned ancient island. Although the possibility of constructional forms cannot be excluded, there is no positive evidence that large guyots are not ancient islands. Using the height of guyots above basement as an indicator of paleobathymetry, Dr. Menard demonstrated that the central western Pacific has always been anomalously shallow. Thus, contrary to the standard thermal model, the Jurassic and early Cretaceous crust is not anomalously shallow because it is old: it was shallow when it was young.

In work on Atlantic upper-water circulation, Dr. Mizuki Tsuchiya found evidence that the South Atlantic subtropical gyre consists of two anticyclonic cells. Maps of geopotential anomaly for the upper 300 m indicate that the two cells are centered at about 22°S and 32°S, separated by a zonal trough just off the coast of South America. This circulation pattern appears to be a permanent feature and is associated with a general poleward-deepening trend of the isotherms below 300 m and a reversed trend in the shallower layer.

Sargun Tont is studying climatic fluctuations as reflected in sea-surface temperature (SST), air temperature, and sea level. Tont examined these variables' relationship to 76 diatom species, using data recorded near the coast of southern California. The abundance of some species (e.g., *Asterionella japonica*) is inversely correlated to SST anomalies, although their occurrences (absence or presence) are independent of SST fluctuations. However, other species (e.g., *Rhizosolenia styliformis*) appear only during anomalously warm years; thus they can be used as tracers of El Niño events. Tont found that the total number of diatoms is significantly correlated with alongshore wind stress.

Dr. Huntley continued land-based studies of particle rejection by marine copepods. He used video recordings as well as traditional feeding studies to find that several species of dinoflagellates were consistently rejected as food. The chemical mechanisms of rejection and its ecological consequences are under study.



ARTIST'S RENDERING of Scripps's new R/V *Robert Gordon Sproul*

SEAGOING OPERATIONS

R/V *New Horizon*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
7/4-7/28/83		Off Oahu, San Clemente, Catalina & Santa Barbara basins	Physiology/current meters	Honolulu, Port Hueneme	J. Childress (UCSB)	T. Desjardins
7/28-7/30/83		Point Conception	Current meter moorings	San Diego	R. Davis	T. Desjardins
8/9-8/28/83	ECHO II	Local	Acoustic backscatter survey	San Diego	F. Spiess/ P. Lonsdale	T. Desjardins
9/14-10/4/83		28°57'N, 122°22'W	Electromagnetic studies	Honolulu	C. Cox/A. Chave	T. Desjardins
10/8-11/6/83		Central/Eastern North Pacific	Benthic biology	San Diego	K. Smith	T. Desjardins
11/12-11/23/83		W. coast of Baja Calif.	Chemical microbiology	San Diego	P. Williams	T. Desjardins
11/29-11/30/83		San Clemente Basin	Sediment trap recovery	San Diego	R. Weiss	T. Desjardins
12/2/83		San Clemente Basin	Manganese nodule project	San Diego	R. Weiss	T. Desjardins
12/5-12/9/83		S. California Bight	El Niño studies	San Diego	W. Bryan	T. Desjardins
1/4-1/25/84	CalCOFI 8401	Southern California, Baja California	Physical, chemical, biological studies	San Diego	T. Hayward	T. Desjardins
2/7-3/4/84	CalCOFI 8402	Central California, Baja California	Physical, chemical, biological studies	San Diego	W. Bryan	T. Desjardins
3/29/84		Local	NSF Inspection	San Diego	NA	T. Desjardins
4/4/84		Local	Equipment test	San Diego	C. Cox	T. Desjardins
4/9-5/4/84	CalCOFI 8404	S. California Bight, Baja California	Physical, chemical, biological studies	La Paz	W. Bryan	T. Desjardins
5/8-5/30/84		Gulf of California	Physical oceanography	La Paz	C. Winant/ N. Bray	T. Desjardins
6/2-6/24/84	CalCOFI 8406	Baja California to San Diego	Physical, chemical, biological studies	San Diego	G. Hemingway	T. Desjardins

TOTAL DISTANCE STEAMED: 31,739.2 nautical miles OPERATING DAYS: 250

R/V *Melville*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
7/25-7/29/83		Local	Equipment test	San Diego	R. Weiss	W. Stow
9/7-10/15/83	PROTEA I	East Pacific Rise	Geology/geophysics	Easter Island	K. Macdonald (UCSB)	R. Haines
10/15-10/23/83	PROTEA II	East Pacific Rise	Transit to Valparaiso	Valparaiso	J. Sempere	R. Haines
10/26-11/1/83	PROTEA III	Valparaiso-Punta Arenas	Transit to Punta Arenas	Punta Arenas	R. Wilson	R. Haines
11/4-12/13/83	PROTEA IV	Scotia, Weddell seas	Ice edge, natural history	Cape Town	D. Ainley (Point Reyes Observatory)	R. Haines
1/14-2/15/84	PROTEA V	Southern Ocean	Geology/geophysics	Cape Town	R. Fisher	W. Stow
2/20-3/30/84	PROTEA VI	Antarctic Peninsula	Biology/physical oceanography	Punta Arenas	E. Shulenberger (San Diego Natural History Museum)	R. Haines
4/1-4/7/84	PROTEA VII	Punta Arenas-Valparaiso	Transit to Valparaiso	Valparaiso	E. Lange	R. Haines
4/10-4/23/84	PROTEA VIII	Valparaiso-Manzanillo	Transit to Manzanillo	Manzanillo	E. Pillard	A. Phinney
4/28-5/21/84	PROTEA IX	East Pacific Rise	Angus deployment	Manzanillo	R. Ballard (WHOI)	A. Phinney
5/22-5/27/84	PROTEA X	Manzanillo-San Diego	Transit to San Diego	San Diego	E. Pillard	A. Phinney

TOTAL DISTANCE STEAMED: 34,624.1 nautical miles OPERATING DAYS: 243

R/P FLIP

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
7/9-7/14/83	OP 143	Local	Vertical array tests	San Diego	R. Williams	D. Efird
8/10/83	OP 144	Local	Hydrophone wire plotter test	San Diego	R. Williams	D. Efird
8/17-9/14/83	OP 145	Local	Vertical array tests	San Diego	F. Fisher/ N. Booth (NOSC)	D. Efird
10/18-11/19/83	OP 146	Local	Mildex equipment test	San Diego	R. Pinkel	D. Efird
4/10-4/13/84	OP 147	Local	Equipment test	San Diego	R. Williams	D. Efird
5/7-5/13/84	OP 148	Local	Equipment test	San Diego	R. Williams	D. Efird
5/18-5/30/84	OP 149	San Diego-Honolulu	Transit to Honolulu	Honolulu	NA	S. Martin
6/14-6/18/84	OP 150	Off Honolulu	Equipment test	Honolulu	R. Williams	D. Efird

OPERATING DAYS: 91

R/V Ellen B. Scripps

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
6/24-7/7/83		San Miguel Island	Mammal studies	San Diego	R. Condit (UCSC)	T. Beattie
7/15-7/16/83		Local	Water sampling	San Diego	W. Bryan	T. Beattie
7/18-7/19/83		Local	Water sampling	San Diego	F. Azam	T. Beattie
7/21-7/25/83		S. California coast	Equipment tests	San Diego	C. Cox	T. Beattie
7/26-7/29/83		Local	Instrument retrieval	San Diego	L. Dorman	T. Beattie
8/6/83		Local	Student cruise	San Diego	R. Wilson	T. Beattie
8/17-8/19/83		Local	El Niño studies	San Diego	W. Bryan	T. Beattie
9/12-9/14/83		Local	El Niño studies	San Diego	W. Bryan	T. Beattie
10/10-10/13/83		Local	El Niño studies	San Diego	W. Bryan	T. Beattie
10/17-10/25/83		Point Conception	Hydrographic work	San Diego	L. Armi	T. Beattie
11/4-11/7/83		Local	El Niño water sampling	San Diego	W. Bryan	T. Beattie
2/13-2/14/84		Local	Transects along the coast	San Diego	M. Mullin	T. Beattie
2/18-3/1/84		Channel Islands	Mammal survey	San Diego	B. Le Boeuf (UCSC)	T. Beattie
3/2/84		Local	Camera test	San Diego	W. Wakefield	T. Beattie
3/3/84		Local	Student cruise	San Diego	R. Rosenblatt	T. Beattie
3/6/84		Local	Electrical studies	San Diego	C. Cox	T. Beattie
3/7/84		Local	Electrical studies	San Diego	C. Cox	T. Beattie
3/14-3/17/84		Local	Electrical studies	San Diego	C. Cox	T. Beattie
3/20/84		Local	Camera test	San Diego	W. Wakefield	T. Beattie
3/21-3/25/84		Local	Seismic tests	San Diego	L. Dorman	T. Beattie
3/30/84		Local	NSF inspection	San Diego	NA	T. Beattie
4/4/84		Local	Camera test	San Diego	W. Wakefield	T. Beattie
4/9-4/14/84		Local	Electrical studies	San Diego	C. Cox	T. Beattie
4/17-4/19/84		Local	Instrument retrieval	San Diego	L. Dorman	T. Beattie
4/23-4/27/84		Local	Electrical studies	San Diego	C. Cox	L. Zimm
5/1-5/2/84		Local	Benthic biology	San Diego	A. Yayanos	T. Beattie
5/4-5/10/84		Santa Monica Bay	Biochemistry tests	San Pedro/San Diego	H. Felbeck	T. Beattie
5/14/84		Local	Equipment test	San Diego	F. Fisher	T. Beattie
5/18-5/21/84		Local	Plankton layer studies	San Diego	M. Mullin	T. Beattie
5/31/84		Local	Equipment tests	San Diego	P. Worcester	T. Beattie
6/2/84		Catalina Basin	Electrical studies	San Diego	C. Cox	T. Beattie
6/12-7/9/84		Sea of Cortez	Mammal studies	San Diego	B. Le Boeuf (UCSC)	T. Beattie

TOTAL DISTANCE STEAMED: 9,413 nautical miles OPERATING DAYS: 115

R/P ORB

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
7/25-7/27/83	OP 82.0	Local	Thruster test	San Diego	R. Horn	T. Hoopes

OPERATING DAYS: 2¼

R/V *Thomas Washington*

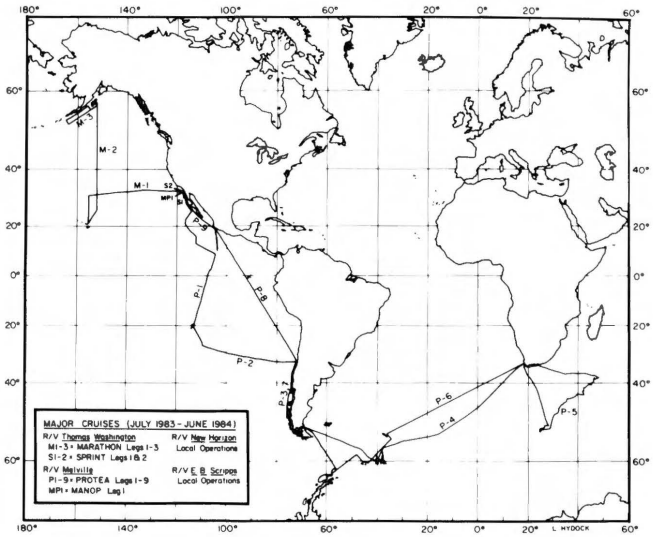
DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
2/21-2/23/84		Popcorn Ridge	Dredging	San Diego	H. Craig	C. Johnson
3/1-3/8/84	SPRINT	Local	Sea Beam seamount surveys	San Diego	P. Lonsdale/ J. Mammerickx	C. Johnson
3/19-3/20/84		San Clemente Island	Sea Beam calibration tests	San Diego	C. de Moustier	C. Johnson
3/24-4/27/84	MARATHON I	Musician seamounts	Ecological energetics	Honolulu	K. Smith	C. Johnson
5/4-6/4/84	MARATHON II	Along 152°W	CTD & hydrographic stations	Kodiak	L. Talley/ R. de Szoeke (OSU)	C. Johnson
6/9-7/9/84	MARATHON III	Aleutian Trench	Sea Beam profile	Kodiak	J. Ladd (LDGO)/ S. Lewis (LDGO)	R. Gregg

TOTAL DISTANCE STEAMED: 16,820 nautical miles OPERATING DAYS: 109

RESEARCH VESSELS OF SCRIPPS INSTITUTION OF OCEANOGRAPHY

	MELVILLE	*NEW HORIZON*	*ELLEN B. SCRIPPS*	*THOMAS WASHINGTON*	FLIP	ORB
TYPE:	Oceanographic research	Oceanographic research	Offshore supply	Oceanographic research	Floating Instrument Platform	Oceanographic Research Buoy
YEAR BUILT:	1969	1978	1964-65	1965	1962	1968
YEAR ACQUIRED BY SCRIPPS:	1969	1978	1965	1965	1962	1968
OWNER:	U.S. Navy	University of California	University of California	U.S. Navy	U.S. Navy	U.S. Navy
LENGTH:	74.67 m	51.81 m	28.95 m	63.70 m	108.20 m	21.03 m
BEAM:	14.02 m	10.97 m	7.31 m	12.00 m	6.09 m	13.71 m
DRAFT:	4.87 m	3.65 m	1.82 m	4.39 m	3.35/91.44 m	fwd. 1.48 m aft. 1.63 m
DISPLACEMENT FULL (Metric tons):	1,882	698	212	1,235	1,359	294
CRUISING SPEED (Knots):	10	10	9	10	varies*	varies*
RANGE (Nautical miles):	9,000	6,000	5,100	9,000	varies*	varies*
CREW:	23	12	5	23	6	5
SCIENTIFIC PARTY:	23-39**	13 or 19**	8, 10 or 14**	22	10	10

1983-84 Total operating days: 810 1983-84 Total nautical miles steamed: 92,596 *Depends on towing vessel **With berthing vans



GRADUATE DEPARTMENT

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

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

Biological Oceanography. Biological oceanographers are concerned with the interactions of marine organisms with the physical-chemical environment. Research and instructional activities in this curriculum range from food-chain dynamics and community structure to taxonomy, behavior, physiology, and zoogeography of oceanic organisms.

Geophysics. This curriculum is designed to educate the physicist (theoretician or experimentalist) about the sea, the solid earth on which the waters move, and the atmosphere with which the sea interacts. The program assists the student in understanding the nature of the earth and in mastering new field, laboratory, and mathematical techniques.

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

Marine Chemistry. Marine chemists are concerned with chemical processes operating within the marine environment: the oceans, the marine atmosphere, and the seafloor. Research programs are based on the interactions of seawater components with the atmosphere and sedimentary solid phases, and with the chemical constituents of marine plants and animals.

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

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

DR. BENJAMIN E. VOLCANI and postdoctoral scholar Dr. J. Richard Ludwig.

Graduate Students and Degree Recipients

In the fall of 1983, 32 new students were admitted to graduate study. Of these, 5 were in marine biology, 6 in geological sciences, 5 in marine chemistry, 7 in geophysics, 3 in physical oceanography, 3 in applied ocean sciences, and 3 in biological oceanography. Enrollment at the beginning of the academic year was 189. Seven Master of Science degrees and 24 Doctor of Philosophy degrees were awarded by UC San Diego to the students listed below.

Doctor of Philosophy Degrees Awarded, with Titles of Dissertations

Earth Sciences

Desiree Beaudry, "Depositional History and Structural Evolution of a Sedimentary Basin in a Modern Forearc Setting, Western Sunda Arc, Indonesia."

Cynthia A. Evans, "Petrology and Geochemistry of the Transition from Mantle to Crust Beneath an Island Arc-Backarc Pair: Implications from the Zambales Range Ophiolite, Luzon, Philippines."

Kevin R. MacKenzie, "Crustal Stratigraphy and Realistic Seismic Data."

John J. Mahoney, "Isotopic and Chemical Studies of the Deccan and Rajmahal Traps, India: Mantle Sources and Petrogenesis."

Robert J. Poreda, "Helium, Neon, Water, and Carbon in Volcanic Rocks and Gases."

Peter R. Shaw, "Waveform Inversion of Explosion Seismology Data."

Marine Biology

James W. Ammerman, "Mechanisms in Bacterioplankton-Organic Matter Interactions."

Marjory E. Clarke, "Feeding Behavior of Larval Walleye Pollock, *Theragra chalcogramma* (Pallas), and Food Availability to Larval Pollock in the Southeastern Bering Sea."

Mary M. Hagedorn, "Social Signals in Electric Fish."

Margo G. Haygood, "Iron Regulation of Luminescence: Implications for the Ecology and Symbiotic Associations of the Luminous Bacteria."

Chia-Wei Li, "Studies on Comparative Morphogenesis of the Cell Wall in Centric Diatoms."

Steven C. Piper, "Biology of the Marine Intertidal Mollusc *Nuttallina,* with Special Reference to Vertical Zonation, Taxonomy and Biogeography."

Raymond R. Wilson, Jr., "Taxonomic and Biological Studies on the Abyssal Grenadiers *Coryphaenoides armatus* and *C. yaquinae* in the Eastern and Central North Pacific, with Special Reference to Otoliths."

Oceanography

Felicity Kim Devonald, "Evaluation of the Feeding Success of Jack Mackerel Larvae off Southern California, and Some Contributing Factors."

Lawrence E. Deysher, Jr., "Recruitment Processes in Benthic Marine Algae."

D. Scott Hansen, "Considerations in Upper Ocean Doppler Velocimetry."

Michael E. Huber, "Ethology and Population Biology of *Trapezia,* a Xanthid Crab Symbiotic with Reef Corals, with Special Reference to Territoriality and Speciation."

Kathryn A. Kelly, "Swirls and Plumes, or Application of Statistical Methods to Satellite-Derived Sea Surface Temperatures."

Steven J. Lentz, "Subinertial Motions on the Southern California Continental Shelf."

Alec D. MacCall, "Population Models of Habitat Selection, with Application to the Northern Anchovy."

José Pelaéz-Hudlet, "Phytoplankton Pigment Concentrations and Patterns in the California Current as Determined by Satellite."

Craig R. Smith, "Enrichment, Disturbance and Deep-Sea Community Structure: The Significance of Large Organic Falls to Bathyal Benthos in Santa Catalina Basin."

Janice E. Thompson, "Chemical Ecology and the Structure of Sponge Dominated Assemblages."

Michael L. Van Woert, "Satellite Observations of Fronts and Frontal Meanders in the Central North Pacific Ocean."

Master of Science Degrees

Earth Sciences	Marine Biology	Oceanography
David S. Garbasz	Jerry D. Jacobs	Guilietta Fargion
Martin C. Kleinrock		Annalisa Griffa
Conrad Van Bruggen		Lauren S. Mullineaux

Eckart Dissertation Prize

DR. DANIEL H. COHN

Dr. Daniel H. Cohn received the 1983 Eckart Dissertation Prize. An annual award of $1,500 is made to the Scripps graduate student whose dissertation is judged the most original and most stimulating among those submitted each academic year. The Eckart Prize was established in 1975 to honor the late Dr. Carl H. Eckart.

Dr. Cohn's thesis, "Isolation, Organization and Expression of the Luciferase Genes from *Vibrio harveyi,*" describes a genetic analysis of the luminescence system in *V. harveyi.* The genes encoding bacterial luciferase, the enzyme catalyzing the light-emitting reaction, were isolated. The nucleotide sequence of the isolated DNA was determined and yielded information on the structure of the protein and the expression of the genes.

FACILITIES AND COLLECTIONS

Shore Facilities

Analytical Facility. Instruments at the facility include a Philips automated X-ray fluorescence spectrometer with computerized control and data analysis; three X-ray diffraction systems, including a Philips APD 3600/02 with computer aided search/match mineral files; a Perkin Elmer atomic absorption/fluorescence spectrometer with heated graphite analyzer and metal hydride systems; a Beckman amino-acid analyzer; a Hewlett-Packard computerized GC/mass spectrometer and four H/P gas chromatographs with EC, FI detectors; two Varian nuclear magnetic resonance spectrometers—a CFT-20 and an EM 360; a Leco CO_2 and SO_2 analyzer; a Coulo metrics total carbon/CO_2 analyzer; a P/E 621 grating infrared spectrometer; a P/E UV-VIS 124 spectrometer; a Cambridge S-4 scanning electron microscope with Ortec EEDS II energy dispersive X-ray spectrometer; an Hitachi H-500 scanning transmission electron microscope with an Ortec EDS X-ray spectrometer; a Zeiss 9 TEM; a Balzer's freeze etch system; diamond knife microtomes; a Cameca "Camebax" electron microprobe with three automated crystal spectrometers, polarized light optics, SEM, TEM capabilities, Ortec EDS X-ray system and a Canberra/DEC computer system.

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

Aquarium Facilities. There are two research aquarium facilities; each is provided with a dual-line system that delivers seawater at ambient temperatures, a single-line chilled seawater system, and compressed air. The Experimental Aquarium (250 m^2) is equipped with 5 rooms for controlled experiments, 20 tanks with capacities from 425 to 2200 liters, 9 seawater trays, counter space, sinks, and lockers. The Marine Biology Aquarium (280 m^2) is equipped with 26 tanks with capacities from 750 to 1500 liters, 16 seawater trays, counter space, and sinks.

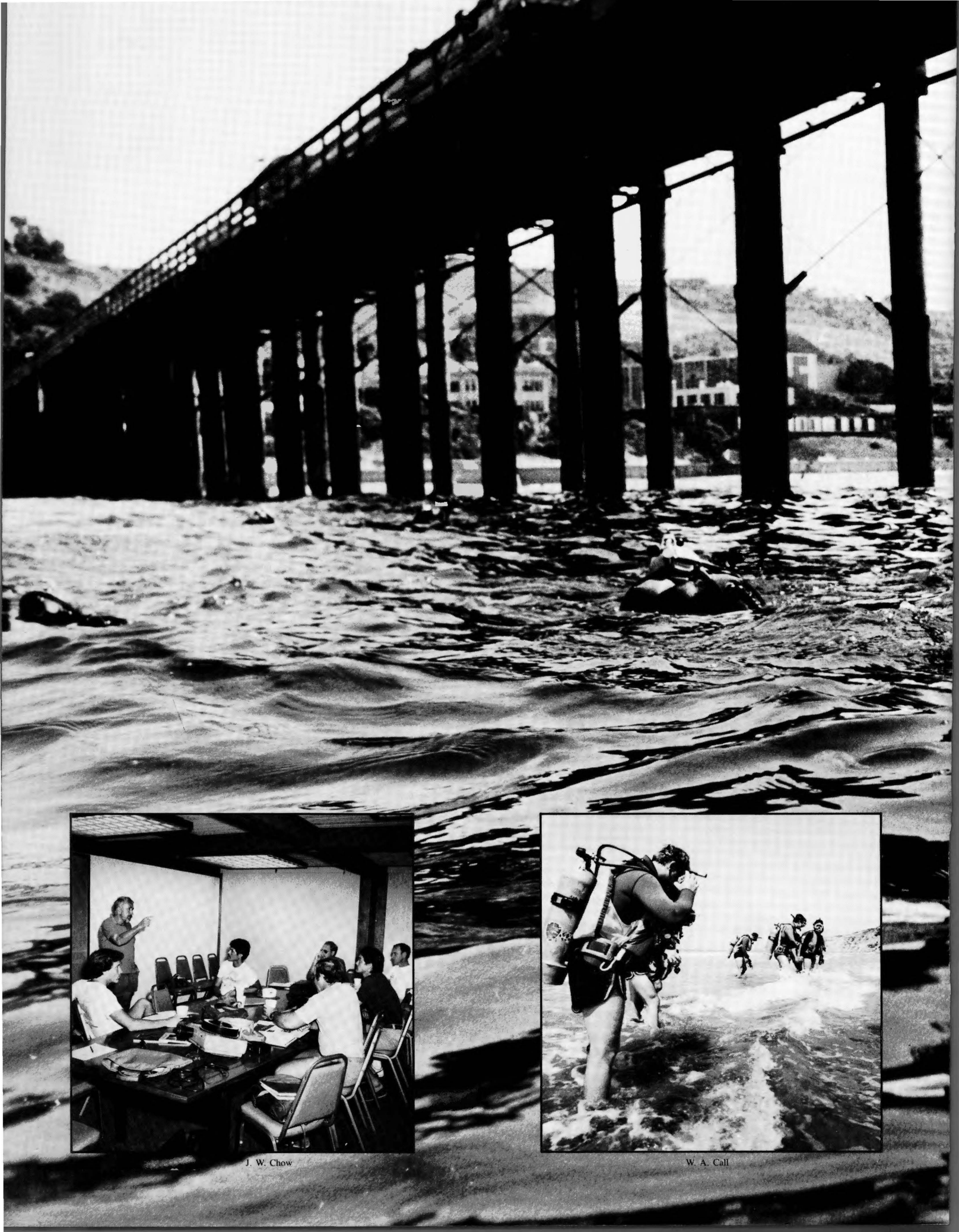
Cardiovascular Research Facility. This facility, shared by the Physiological Research Laboratory and the UC San Diego School of Medicine, consists of an experimental animal colony, equipment for measuring circulatory and cardiac functions in conscious unrestrained animals, and an instrumentation development laboratory.

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

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

Hydraulics Laboratory. This laboratory has a wind-wave channel 43x2.4x2.4 m, with a tow cart for instruments and models; a two-layer stratified flow channel, test section 1.1x1.1x16 m; a 15x18-m wave-and-tidal basin with an adjustable simulated beach; a 40-m glass-walled wave-and-current channel; a granular fluid mechanics test facility that consists of a 6x12x3-m concrete basin, a 10x1x1-m fluidizing channel, three sand-storage and calibration tanks each 4 m high by 5 m in diameter, all serviced with a high-flow, slurry pumping system; a 16-m oscillating flow tunnel; and an insulated, refrigerated, cylindrical seawater tank 10 m deep and 3 m in diameter equipped with an artificial lighting system. All wave generators in the laboratory incorporate servo systems and can be controlled by computer or magnetic tape. Microcomputer-based data acquisition and data processing systems are used in conjunction with the various facilities.

Kendall Frost Mission Bay Marsh Reserve (Mission Bay, San Diego). Approximately 20 acres of Mission Bay marshland belong to the university and constitute a marsh preserve and wildlife refuge designated for teaching and research. The reserve is a unit of the University of California Natural Land and Water Reserve System. A small laboratory is located on the preserve.



J. W. Chow

W. A. Call

DIVERS FROM THE NATIONAL PARK SERVICE, undergoing Scripps's Scientific Diver Training Program, resurface alongside the Scripps Pier. *Bottom, left to right,* Diving Officer James R. Stewart discusses Antarctic and cold-weather diving; divers undergo rescue training; National Park Service divers begin an underwater navigational swim, and Stewart explains underwater compass use.

J. W. Chow

J. Jones

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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.

Marine Technology Group. This administrative organization comprises the Shipboard Computer Group, resident technicians, geophysical technicians, the Prime Computer Facility, and the Geological Data Center.

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 systems installed on the ships. These computers are installed permanently on the R/V *Thomas Washington* and R/V *Melville,* and they are interfaced to navigational and scientific instruments, including the R/V *Thomas Washington* Sea Beam system.

Resident technicians are knowledgeable guides who dive, rig, handle explosives, operate geological sampling gear (box corers, piston corers, dredges, etc.), operate net tows and trawls, and perform a wide variety of other tasks. They also handle logistics for distant expeditions, and receive and store scientific equipment for future cruises.

The geophysical technicians provide and operate the analog and digital seismic reflection systems using airguns or waterguns and refraction systems.

The Prime Computer Facility is centered on a Prime 750, which is well adapted to economical number-crunching with three megabytes of memory, 1500 megabytes of disk, an array processor, and a variety of peripheral equipment. Its use is primarily by CRT terminals.

The Geological Data Center (described in Special Collections) is also part of the Marine Technology Group.

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

Petrological Laboratory. This facility provides thin-sectioning, microprobe sample preparation, and rock-surfacing services to staff, students, and associated research groups. All types of submarine and subaerial igneous, metamorphic, and sedimentary materials in various states of lithification are prepared here with plastic-vacuum techniques and other types of impregnations.

Physical and Chemical Oceanographic Data Facility (PACODF). PACODF provides a wide range of data and sample collecting services to investigators from Scripps and other institutions. PACODF also maintains an inventory of water samplers and other equipment, which is available at cost to qualified users. The more sophisticated or costly equipment may be used only when accompanied by PACODF technicians who operate and maintain the equipment at sea.

The group participates in expeditions by making high-precision hydrographic measurements, specializing in Neil Brown Instrument Systems CTD (conductivity, temperature, depth) work, and shipboard determinations of salinity, dissolved oxygen, nutrients (silicate, phosphate, nitrate, and nitrite), alkalinity, and total CO_2 from water samples collected with multiple-bottle samplers. The group maintains four sizes of nonmetallic water samplers, ranging from 1.7 to 30 liters. Up to 36 samplers have been deployed at a time, and 48-bottle units are being developed. Larger-volume samplers (270 liters) are available in stainless steel for acquiring radiocarbon or other isotopic samples. A large winch holding 10,000 m of conducting wire is operated by PACODF on expeditions when a requirement for deep casts with heavy sampling equipment cannot be met with the ship's gear.

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

A new IBM 9000 computer system is undergoing software development for both shipboard and shore-based data processing. Tape drives, plotters, and printers are in use with both seagoing and shore-based systems.

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

Radio Station WWD. Owned and operated by Scripps and licensed to the National Marine Fisheries Service (NMFS), station WWD provides worldwide communications services to Scripps, NMFS, and other governmental and university ships. Weather advisories are routinely provided to the fishing fleet as well as to scientific vessels. Western Union services (TWX-Telex) are provided to the San Diego campus.

San Vicente Lake Calibration Facility (48 km from Scripps). This facility, operated by the Marine Physical Laboratory, is equipped for testing and calibrating acoustic transducers used in oceanographic research. The equipment

is located on an 8x15-m enclosed platform in water 40 m deep and offers an unobstructed range of 1,372 m.

Satellite-Oceanography Facility. This facility enables oceanographers to directly receive and process satellite imagery. Data transmitted in real time by the NOAA and NIMBUS polar orbiting satellites are received by the 5-m tracking antenna and stored on computer-compatible tapes. In addition to real-time coverage, retrospective archives of worldwide data are also available. The most commonly used sensors include the Advanced Very High Resolution Radiometer (AVHRR) and Coastal Zone Color Scanner (CZCS), which provide information in the infrared and visible portions of the spectrum. Scanning Multichannel Microwave Radiometer (SMMR) data, from which sea-surface winds may be derived, are also processed at the facility. The system central processor is an HP 3000 Series II computer dedicated to the facility. This processor has 2 megabytes of main memory and 250 megabytes of disk storage. Tape drives capable of operating at 800, 1600, or 6250 bpi densities 317 cm per second assure complete versatility. A high-resolution color display station allows the user full interaction with the satellite imagery at near-real-time rates for most common operations. Current applications include tracking of drifting buoys via the ARGOS data collection system, near-real-time support of research vessels and aircraft by remote detection of chlorophyll concentrations, and sea-surface temperature determination. A four-day course, taught every quarter by the facility staff, gives potential users an overview of the available tools as well as several hours of hands-on experience.

Scripps Library. The library has outstanding collections in oceanography, marine biology, and marine technology. It also specializes in publications on atmospheric sciences, fisheries, geology, geophysics, and zoology. The library currently receives more than 3,400 serial titles and has a cataloged collection of more than 80,000 volumes, including an extensive documents, reports, and translations collection, and a rare book collection with numerous accounts and journals of famous voyages of discovery. There is also a large map and chart collection emphasizing nautical information.

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

Scripps Pier. The 305-m pier serves as a launching site for small boats used for local oceanographic work, provides space for on-site studies, and supports the seawater system that supplies the aquaria and laboratories.

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

Thomas Wayland Vaughan Aquarium-Museum. The aquarium-museum helps to increase public understanding and appreciation of the ocean through museum displays on oceanographic topics, a variety of educational programs, and exhibits of living marine animals from local waters and from the Sea of Cortez.

Scientists at the aquarium-museum study marine animal maintenance systems, fish coloration, and fish diseases. Through its collecting facility, the aquarium supplies scientists with living specimens.

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

A public membership group, the Scripps Aquarium Associates, provides lecture series, local and foreign study excursions, and a quarterly newsletter.

Underwater Research Areas include:

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

Scripps Submerged Land Area. This area of approximately 3.25 km^2 is leased by the University of California from the city of San Diego. It lies seaward and to the north of Scripps.

Special Collections

Benthic Invertebrates. The collection contains some 28,000 lots of specimens sorted into major taxonomic groups such as Coelenterata, Echinodermata, and Mollusca. All are accessioned with collection data, and more than 35 percent are identified to species. Several catalogs of holdings (Decapod and Stomatopod Crustacea [SIO Ref. No. 77-9], Brachiopoda [SIO Ref. No. 78-19], and Echinodermata [SIO Ref. No. 82-5]), as well as specimens, are available to qualified students and researchers.

Deep Sea Drilling Project (DSDP) Core Repository. Scripps houses the West Coast Repository for cores collected by DSDP from the Pacific and Indian oceans. Core samples are made available to qualified researchers throughout the world under policies established by the National Science Foundation.

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

Geological Data Center. Most of the geological/geophysical data collected by Scripps vessels while under way are processed and archived here. Navigation, depth, magnetics, and Sea Beam data are computer-processed for entry into the digital data base and for production of cruise reports and plots. Seismic profiler records are microfilmed, blown back at reduced scale, and reassembled by geographic area to permit rapid retrieval and evaluation. Index track charts, with overlays of the various data types, contain more than a million nautical miles of Scripps cruises, as well as tracks of DSDP's *Glomar Challenger*. The data center also maintains a multidisciplinary index of all samples and measurements made on major Scripps cruises.

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

Marine Invertebrates. Included in this collection of more than 60,000 documented whole zooplankton samples are accessioned holdings from the continuous CalCOFI program, expeditions, and special projects. Samples represent zooplankton, collected with nets, ranging from surface neuston to bathypelagic mid-water trawls. The major emphasis of the collection has been in the northeastern Pacific, but an increasing number of samples are also available from other oceanic and continental slope regions. The collection includes identified specimens for some of the major taxonomic groups. Samples are supplemented with physical and chemical data.

Marine Vertebrates. This collection contains more than 2 million specimens, with 3,200 cataloged species, including 128 primary types. Approximately 500 collections are added each year. Although the collection is worldwide, it specializes in deep-sea and eastern Pacific shorefishes. It contains large holdings of shorefishes from the Gulf of California and Panama and an extensive skeletal collection of dried preparations and cleared-and-stained specimens in glycerin.

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

Temperature and salinity records, taken daily, and records for various years from other California shore stations, along with data from more than 20,000 hydrographic casts from Scripps cruises, are managed by the Physical and Chemical Oceanographic Data Facility.

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.

W. A. Call

AERIAL VIEW of the new Physical Oceanography and Space Science Building

APPENDIXES

A

Publications

Introduction

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

Below is a complete listing of Scripps publications for fiscal 1984. Detailed information on the availability of each series is included.

Bulletin

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

The most recent volumes are listed below.

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

v.25 **Wilson,** George D. F. Systematics of a Species Complex in the Deep-Sea Genus *Eurycope,* with a Revision of Six Previously Described Species (Crustacea, Isopoda, Eurycopidae). 1983. 68p.

CalCOFI Atlas Series

The *California Cooperative Oceanic Fisheries Investigations* (CalCOFI) *Atlas Series* provides processed physical, chemical, and biological measurements of the California Current region. The series reflects the work of the CalCOFI program, in which Scripps cooperates with the California Department of Fish and Game and the National Marine Fisheries Service.

These atlases are distributed at no charge to research institutions, university libraries, and qualified research scientists active in oceanographic fields relating to the CalCOFI program. Editions are limited to 650 copies. Institutions or libraries interested in acquiring atlases should write to: Dr. Abraham Fleminger, Scripps Institution of Oceanography, A-001, La Jolla, California 92093.

The most recent atlas issued is listed below.

No. 30 **Lynn,** R. J., K. A. **Bliss** and L. E. **Eber.** Vertical and horizontal distributions of seasonal mean temperature, salinity, sigma-T, stability, dynamic height, oxygen, and oxygen saturation in the California Current, 1950-1978. August 1982. 527p.

Contributions

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

The articles listed below were published in the 1983 volume and may be found in the publications cited. Information about a specific reprint can be obtained by writing directly to the author in care of: Scripps Institution of Oceanography, La Jolla, California 92093.

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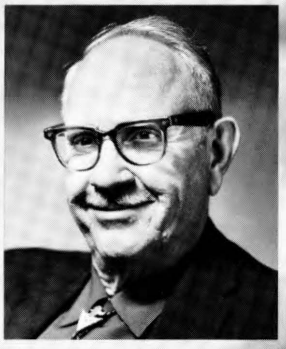
IN MEMORIAM

Kenneth S. Cole. April 18, 1984. He had been an adjunct professor of neurosciences and part of the neurobiology unit since 1982.

Denis L. Fox. September 4, 1983. He was one of the founders of marine biochemistry in the United States. He was most widely known for his animal pigmentation studies. He held a continuous appointment at Scripps from 1931 until his death.



George R. Lee. August 26, 1983. He served as the Visibility Laboratory's business officer from 1961 until his retirement in 1976.

Steven S. Pawka. October 7, 1983. He was a research oceanographer in the Center for Coastal Studies. He received his doctorate from Scripps in 1982 and was studying the directional properties of surface gravity waves.

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Dr. Edward D. Goldberg
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Dr. Miriam Kastner
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Dr. Devendra Lal
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Dr. Reuben Lasker
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Dr. Jerome Namias
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Dr. Roger R. Revelle
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Received an honorary Doctor of Science degree from Old Dominion University, Norfolk, Virginia.

Dr. Francis P. Shepard
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Other	19,249	7,486	—	—	26,735	—
Total Federal Government	36,159,095	1,786,664	2,869,228	346,090	41,161,077	73.6
STATE AND UNIVERSITY FUNDS	8,589,413	346,312	641,519	575,912	10,153,156	18.1
LOCAL GOVERNMENT	13,881	—	9,616	—	23,497	—
PRIVATE GIFTS AND GRANTS	2,598,406	157,797	351,099	5,899	3,113,201	5.6
ENDOWMENT FUNDS	402,689	28,063	7,178	11,709	449,639	.8
SERVICES, RESERVES, AND MISC.	913,464	(2,093)	155,010	5,415	1,071,796	1.9
Total Current Funds Expenditures	$48,676,948	2,316,743	4,033,650	945,025	55,972,366	100.00

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

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