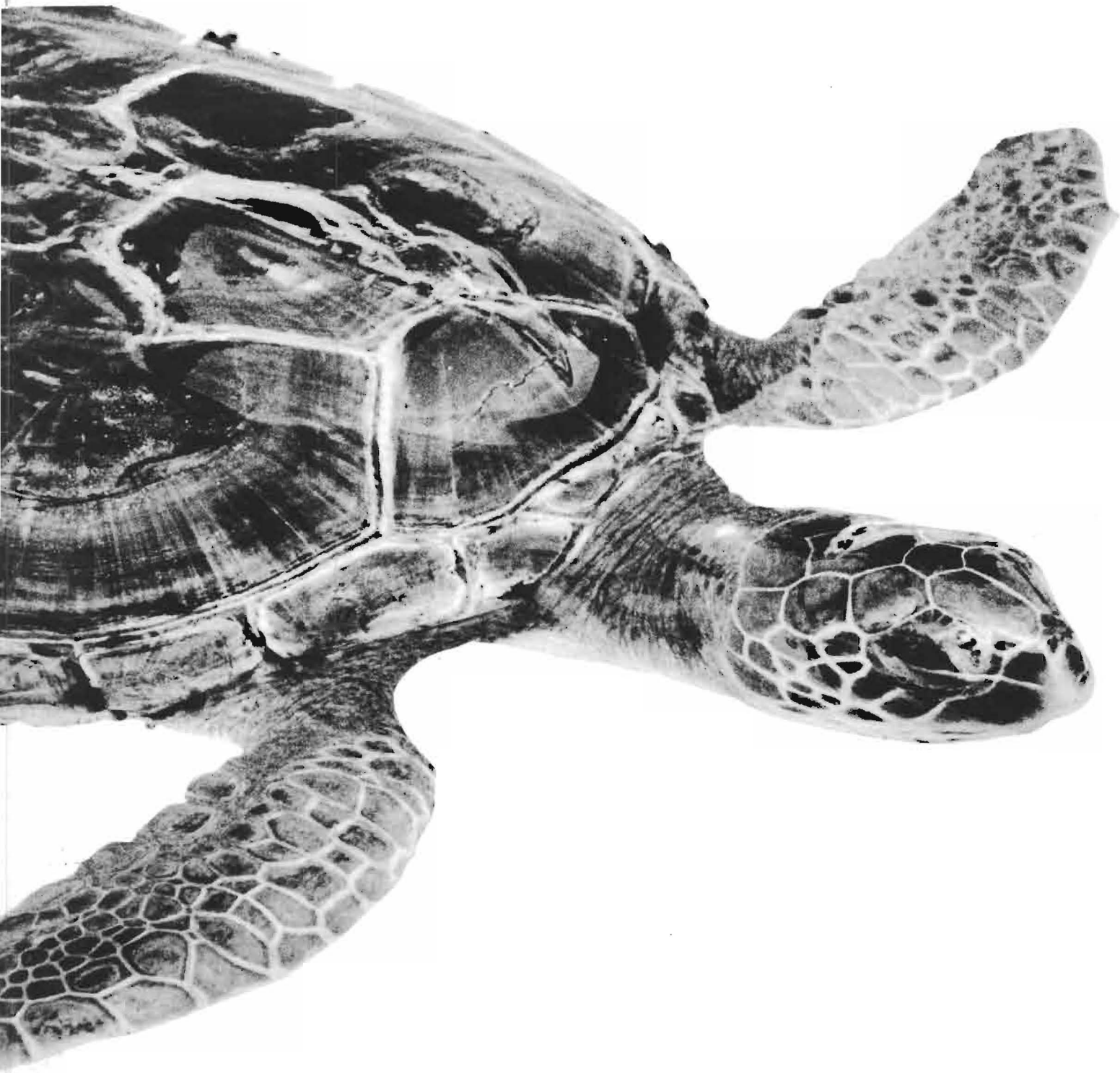


UCSD

Scripps Institution of Oceanography

Annual Report 1983

University of California, San Diego

DEDICATION

Dr. Theodore H. Bullock is a peripatetic professor of comparative neurophysiology. Amongst his first travels from his home in China was a visit to his maiden aunt, Mary Beckwith, in La Jolla. Her love of shell collecting fired Ted's first sparks of interest in marine science.

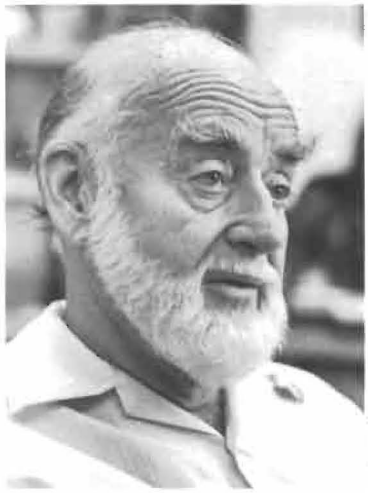
Once his missionary family returned to the United States, that scientific interest flamed. Ted spent four summers at the Pomona College Marine Laboratory at Laguna Beach and did part of his doctoral thesis at Scripps. He took his Ph.D. in zoology at the University of California, Berkeley in 1940.

His research, which has taken him from Bikini to Yugoslavia, and from Japan to Brazil, centers on brain function in marine animals. He has studied behaviorial neurophysiology of electroreception in electric and nonelectric fish, brain waves in octopuses and rays, and the auditory systems of porpoises, sea lions, penguins, manatees, and sharks.

A National Academy of Science member, Ted was the ninth recipient of the Karl Spencer Lashley Prize, awarded by the Council of the American Philosophical Society for "his useful and significant work in neurobiology."

Ted came to Scripps in 1966, after twenty years as a professor of zoology and member of the Brain Research Institute at the University of California, Los Angeles. He has been chairman of the Scripps Neurobiology Unit since 1969.

Dr. Bullock has always felt close to Scripps. He is proud to say he has known and had scientific discourse with every director of Scripps, from William E. Ritter to William A. Nierenberg.



Dr. Theodore H. Bullock

L. D. FORD

Dr. Theodore H. Bullock at work on giant nerve fibers in annelid worms in his University of Missouri laboratory in 1946.

University of California, San Diego
Volume 17, Number 1, January 1984

Librarians please note: the words "annual report" were dropped from the title with the 1976 edition and are now being added.

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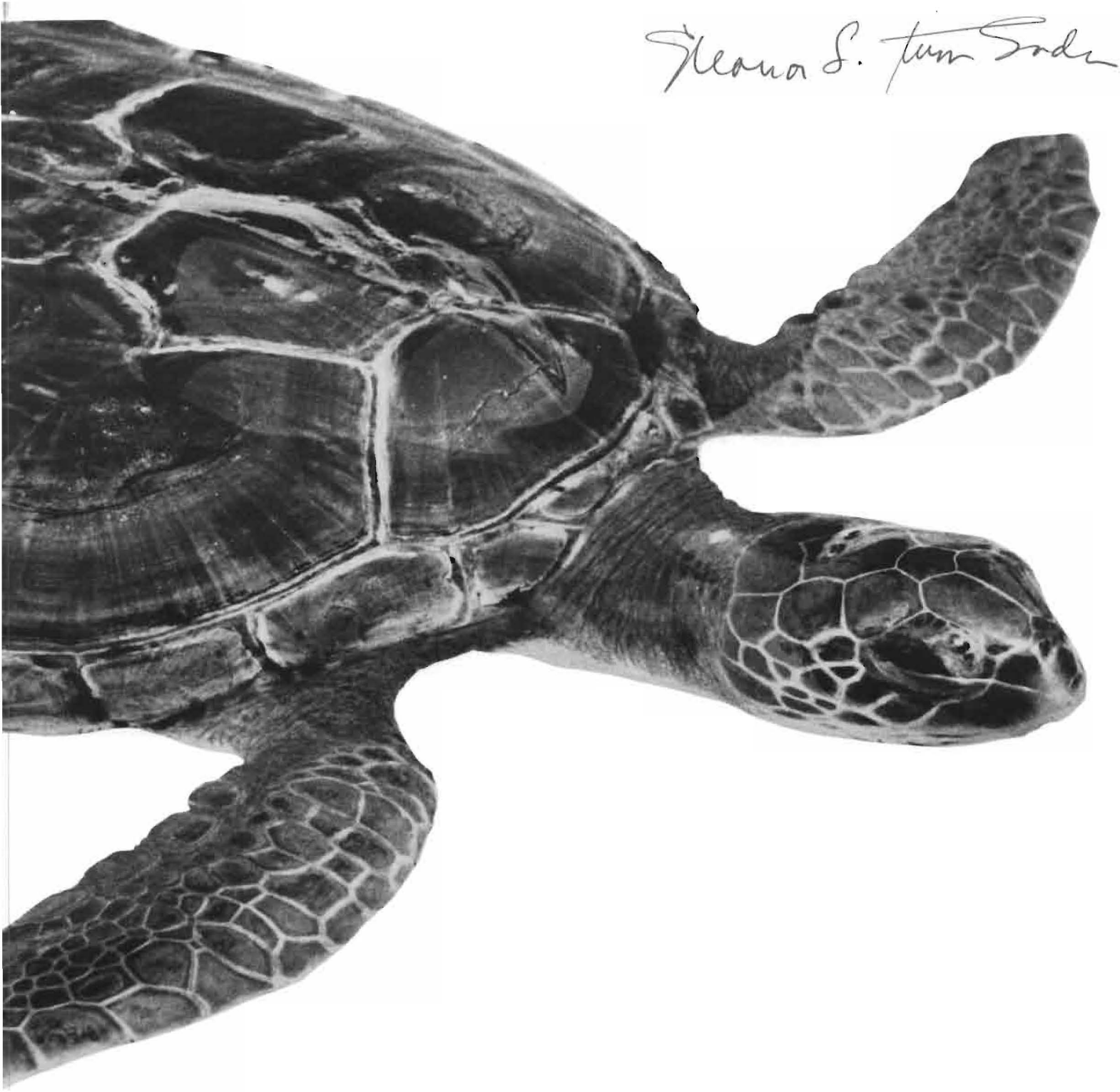

Eleanor S. ten Broek

UCSD

Scripps Institution of Oceanography

Annual Report 1983

University of California, San Diego

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INTRODUCTION

This last year was our seventy-ninth since the formal incorporation of the original institution. As a result of much discussion, we decided to have an eightieth celebration for the coming year. The odd choice was to give senior members of the institution and all the past and present chancellors of UCSD the opportunity to put down their thoughts and predictions for the hundredth anniversary of the institution's founding, which will certainly be a big event. Their comments are to be stored in a time capsule as part of the cornerstone ceremony for the new Physical Oceanography and Space Science Building. They will be opened and reread in the year 2003.

Perhaps the most significant policy change in the institution is related to central and ship computing. It would seem that every five years there is a dramatic change in approach. The last one was the introduction of the Prime computing system eventually including an array processor and greatly expanded memory, disc, and tape capabilities. It served the large users as well as the myriad lesser ones. There are over four hundred accounts on the computer, most of which are active.

However, to better meet the growing needs of the SIO community, support has been provided to the few "number crunching" groups to get their own facilities. This program is well under way and appears successful in its goals. An unexpected fall was the realized possibility of reducing the charge on the Prime by a factor of two.

I can only predict that five years from now we will be looking toward acquiring a facility comparable to a Cray or Cyber 205, but only if the cost drops significantly.

Certainly the most exciting event for SIO this last year was the visit of Queen Elizabeth and Prince Philip. The visit was covered in excruciating detail by the media, and I will only put down what has not been up to now. My first information came from Jim Moss in the Mayor's office in December. He told me that Queen Elizabeth was coming to San Diego in February and would arrive at the Broadway Pier. I said that was impossible, she was too large, that she would never make the channel. I thought, of course, that he meant the QE2! It finally got through to me that he meant the real queen of England and that she was arriving on *Britannia*. We were very flattered to learn that the only specific San Diego request of the royal couple was for a visit to the Scripps Institution of Oceanography.

We had our usual quota of honors this past year. A significant one was the simultaneous election of Jerry Namias to the National Academy of Sciences and the American Academy of Arts and Science. Another important event was a two-day symposium in honor of Walter Munk, one of Scripps's greats.

William A. Nierenberg

William A. Nierenberg, Director
Scripps Institution of Oceanography

J. M. SWANSON

Dr. Nierenberg presents Queen Elizabeth of England with a memento of her visit to Scripps on February 26, 1983.

MARINE NATURAL PRODUCTS CHEMISTRY

The senses of sight and hearing are so well developed in humans that we have relegated the senses of taste and smell to minor, almost esoteric, roles in daily life. In an environment with far less light, and limited sound transmission, marine organisms rely more heavily on chemical messages to transmit information both to other individuals of their own species and to potential predators and prey. Just as humans can smell minute concentrations of chemicals in air, so the animals of the oceans can detect very low concentrations of specific chemicals in seawater. While acknowledging that their research is in the formative stages, Scripps chemists Drs. D. John Faulkner and William H. Fenical believe that chemical messenger compounds influence both the behavior of individual animals and the structure of marine communities.

Marine organisms use special chemicals called secondary metabolites for a variety of purposes. Most frequently the secondary metabolites are used to protect an organism from predators, both large and small. Seaweeds and many marine animals that cannot move from place to place (known collectively as sessile organisms) must defend their living space against competitors that could smother them. It is a great advantage for a sessile organism to be able to produce chemicals that immobilize the larvae of other species that might settle on its surface and eventually prevent its growth. This is in addition to the obvious need to deter mobile animals that feed on sessile organisms. In general, the functions of chemical defense mechanisms are to kill small competitors or to warn larger predators "Don't eat!"

The chemicals produced by marine plants and animals, known collectively as marine natural products, often contain the halogen elements chlorine, bromine, or occasionally iodine, attached to a carbon framework. Terrestrial natural products rarely contain halogens. The presence of halogens in marine natural products reflects the high levels of chloride and bromide ions in seawater. Over 600 halogenated products are fabricated by marine bacteria, red algae, some coelenterates, and sponges. For example, the red seaweed *Asparagopsis* produces copious quantities of halomethanes such as bromoform, chloroform, and carbon tetrachloride. Recent concern over the fate of the halomethane refrigerants known as "freons" in the atmosphere has drawn attention to the occurrence of natural halomethanes released into seawater.

Halogenated organic chemicals are most frequently read about in accounts of the detrimental effects of industrial chemicals. Many synthetic insecticides and herbicides are chlorinated chemicals. The halogenated marine natural products are not nearly as toxic to humans or as environmentally persistent as the halogenated insecticides and herbicides, but they appear to serve a similar purpose in the marine environment, where they are toxic to many other species and can thus deter predators. On the other hand, some invertebrates have evolved a resistance to these general chemical defenses, and the unique chemical properties of halogenated marine natural products make it possible to trace individual chemicals through the marine food web. Using halogenated compounds as tracers, the researchers have determined the diets of individual California sea hares *(Aplysia californica)* by comparing the chemicals found in the sea hare with those of local red algae.

The green seaweeds that abound in tropical oceans provide another example of adaptations involving chemical defense. To survive in these herbivore-intense habitats, many green seaweeds produce terpenoids with potent "anti-herbivore" activities. The abundance of these seaweeds reflects their successful chemical defense strategies. Since many species such as *Halimeda* are highly calcified, their successful proliferation can be directly linked to the evolution of coral reef habitats.

Marine sponges are sessile soft-bodied animals that could easily be smothered by faster growing competitors or eaten by predators. The production of toxic chemicals represents one method of controlling competition and predation. The least-fouled sponges produce the most effective antimicrobial metabolites that presumably act as antifouling agents. Some sponges that burrow into living coral heads use chemicals aggressively by exuding toxins in a mucus that flows down the sponge and spreads around the base to maintain a zone of dead coral around the sponge's burrow.

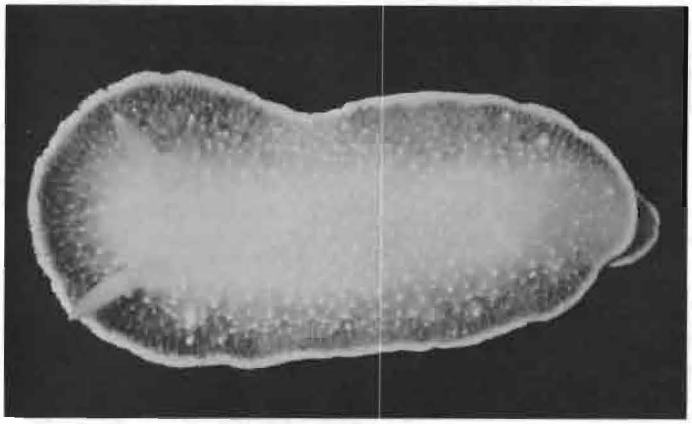
The only major predators of sponges are the colorful dorid nudibranchs. Some nudibranchs have become specialist spongivores and are not deterred by sponge metabolites. Furthermore, the dorid nudibranchs have evolved the ability to use the sponge metabolites for their own defense. When attacked, some nudibranchs excrete diet-derived chemicals that cause the predator to reject the nudibranch and seek less distasteful food. The ability to use defensive chemicals fabricated by sponges gives nudibranchs a "free" defense mechanism and may have enabled them to dispense with the heavy shell that protects most other gastropod molluscs.

Similarly, whole groups of corals have abandoned their classical physical defense, calcification, in favor of an arsenal of chemical deterrents. The octocorals, which consist of sea fans, sea whips, and sea pens, among others, possess no external hard structure and are soft and seemingly easily preyed upon. These organisms escape being eaten, however, and their immunity is now known to involve an effective system of chemical defense.

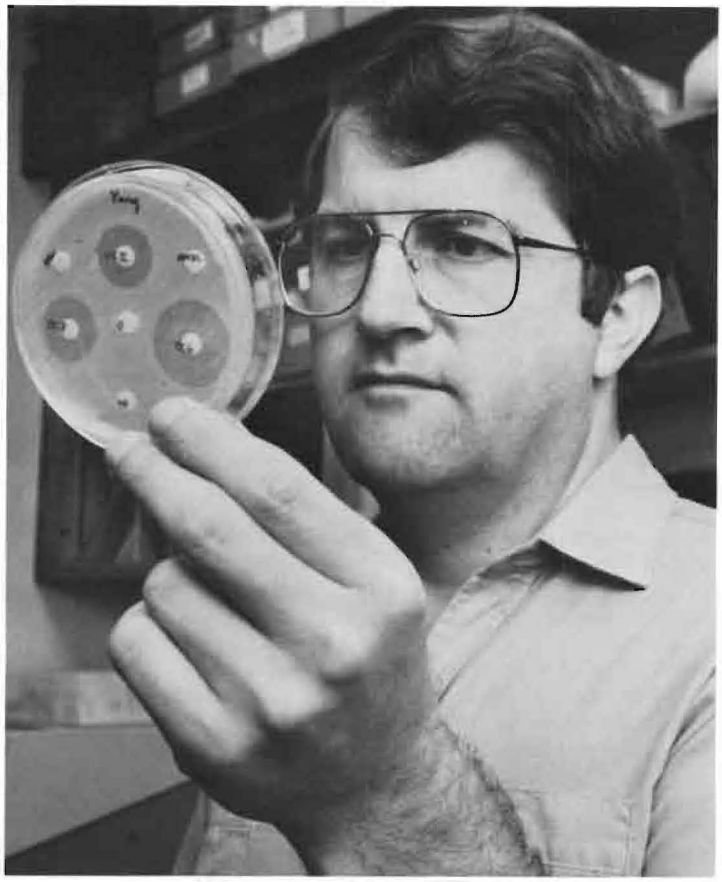
A characteristic of chemical messenger compounds is that they are effective at low concentrations. Thus they must have a very pronounced effect on the sensory apparatus of the target organism. These same compounds may therefore be equally effective against terrestrial targets such as agricultural pests and human diseases. Knowledge that a chemical profoundly affects organisms in its natural environment makes the chemical a better candidate for a drug screening program.

In collaboration with pharmacologist Dr. Robert S. Jacobs of UC Santa Barbara, the Scripps chemists have established a program to screen the novel marine compounds for their pharmaceutical potential. This program has uncovered some remarkably active new pharmaceutical agents. A surprisingly large number of marine products are cytotoxins—chemicals that inhibit cell development and might eventually find use in cancer chemotherapy. One such find is stypoldione, a highly effective cytotoxin first described as an ichthyotoxin that prevented fish from consuming the brown alga *Stypopodium zonale*. Sponges and soft corals have also contributed potential anti-inflammatory agents, some as effective as cortisone and indomethacin. A chemical like

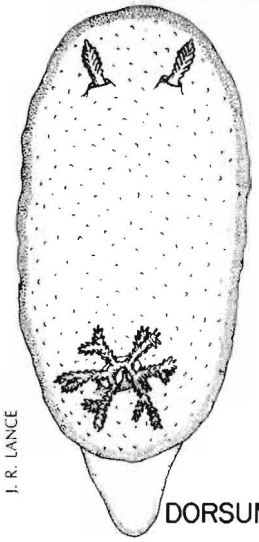
R. P. WALKER

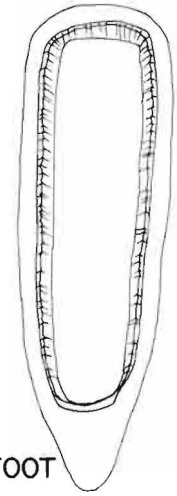


J. E. THOMPSON

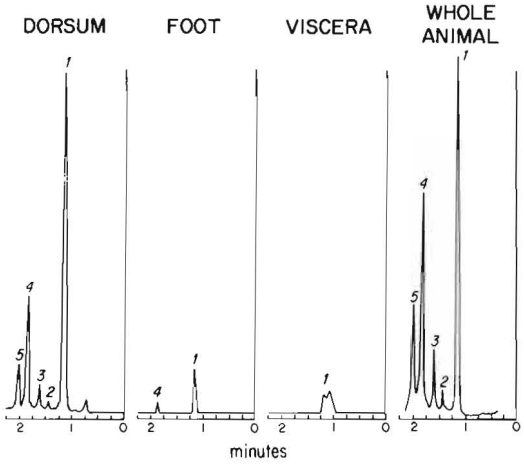


L. D. FORD





J. R. LANCE



Top left: A sponge-dominated marine community where sessile organisms compete for space. Top right: Dr. D. John Faulkner examines the results of antimicrobial screening of extracts from marine sponges. Middle left: The dorid nudibranch Cadlina luteomarginata *(from above). Bottom: Dissection of* C. luteomarginata *into dorsum, viscera, and foot, followed by analysis of the chemical constituents by high-performance liquid chromatography, indicates that the defensive chemicals found in the whole animal are localized in the dorsum.*

lophotoxin from the gorgonian coral *Lophogorgia* sp. is too toxic for drug use but can be used to further our knowledge of human biochemistry and the action of other drugs. These are just the highlights of a program that has found pharmacological potential in over half the compounds tested. This unusually high rate of return is a direct result of the use of chemicals for communication and defense in the marine environment.

The future holds many exciting prospects. Pharmaceutical companies are now testing and refining marine natural products to produce effective and safe medicines. For safety's sake, however, the exhaustive testing procedures will occupy many years before a marine medicine is available. Marine chemicals that are toxic to crustaceans may find a role as insecticides. Knowledge of exactly how marine animals prevent fouling will enable us to apply the same chemical systems to prevent fouling of ships' hulls. But despite all these potential uses, the scientists will derive the greatest satisfaction from knowing exactly how chemicals influence ocean inhabitants.

SEA BEAM MAPPING WITH R/V *WASHINGTON*

R/V *Thomas Washington* became unique in the academic research fleet when, in the fall of 1981, a Sea Beam bathymetric mapping system was installed. The enthusiasm of geologists for exploiting this million dollar equipment has meant that most of the 75,000 miles steamed since installation have been devoted to geologic mapping, although *Washington* retains her versatility for a full range of oceanographic work.

Sea Beam represents a major advance over conventional echo-sounders in several respects. Instead of a single sonar beam producing a profile of the relief beneath the ship it has a swath of 16 beams, which cover the sea floor up to a mile on either side of the ship's track. Each beam is focused on a small area, so that small topographic elements can be resolved. All the soundings are automatically processed, recorded, and positioned by computer, eliminating the tedious and time-consuming "echo-sounder watch" of earlier generations. The data are machine-contoured for almost immediate display, both as plots of contours along the track and on Mercator charts, where several adjacent tracks can be fitted together to build bathymetric maps. The accuracy and resolution of these maps had previously been attainable only for tiny areas where deeply towed sonar systems like our Deep Tow can be employed.

Our early surveys provide a biased sample of the sorts of geologic problems amenable to Sea Beam, because we have rushed to study some plum targets in the eastern subtropical Pacific. These surveys only hint at the system's potential as a supporting tool during sampling operations. Some of the more routine applications have included site surveys for Deep Sea Drilling Project coring, and for submersible diving. In deep water Sea Beam can survey about 40 square kilometers per hour, so with careful positioning of the ship's tracks 5,000 square kilometers of sea floor can be mapped in three days. For sampling operations conducted from *Washington,* a preliminary survey is not always necessary; instead, the real-time display of the relief profile beneath the ship has been used to position dredges onto small volcanoes, corers into sediment ponds, and water samplers onto the crest of the East Pacific Rise.

The attraction of the East Pacific Rise—the crucial structure where most of the Pacific floor is being created at rates of up to 15 cm per year —proved so strong that two-thirds of Sea Beam's 14 cruise legs have been devoted to the study of its crest. Drs. Peter Lonsdale, Ken Macdonald, Dick Hey, Jeff Fox, Harmon Craig, and Jean Francheteau have investigated the rise crest for more than 6,000 km from Mexico to far south of Easter Island. The general pattern of the rise crest had previously been mapped from conventional sounding lines (often widely spaced in the remoter southern regions), and its detailed morphology was known only at a few 20-km-long segments where Deep Tow observations had shown that the spreading axis was marked by a narrow belt of volcanic eruptions. This axial volcanism builds a low ridge oriented precisely at right angles to the direction of sea floor spreading. With Sea Beam, the ridge proved easy to identify, and *Washington* spent many days chasing it up the rise. Fortunately the entire axial ridge is just about 2 km wide, and fits within one Sea Beam swath, so a single track can provide a complete survey.

To summarize the immediate results of the Sea Beam surveys on the rise crest, they have defined the exact location and orientation of the spreading center, extended high-resolution coverage beyond the tiny patches previously examined with towed systems so as to add a third, longitudinal, direction to rise-crest studies; and discovered previously unsuspected structures. One major discovery was the presence of small "nontransform offsets" where overlapping volcanic fissures are laterally displaced by a few kilometers without the theorized strike-slip faulting. These results have implications for such fundamental geologic problems as the source and supply routes of molten rock that feeds the expanding ocean crust and to practical questions such as the likely locations of mineral deposits formed by hydrothermal cooling of the crust.

Similar results have flowed from our Sea Beam mapping of other types of plate boundary: Lonsdale, Macdonald, and Fox have mapped large fast-slipping transform faults, and Tom Shipley and Greg Moore have mapped trenches. The advent of Sea Beam has not replaced the need for deeply towed survey systems, whose multisensor observations are often required for geologic interpretation of the Sea Beam bathymetry; and Sea Beam discovery of unpredicted complexities in plate-boundary structures has stimulated requests for follow-up surveys with these new higher resolution systems. Simultaneous employment of Sea Beam and either the Scripps Deep Tow or the Lamont Seamarc vehicles proved to be an effective survey strategy on a few of the cruise legs.

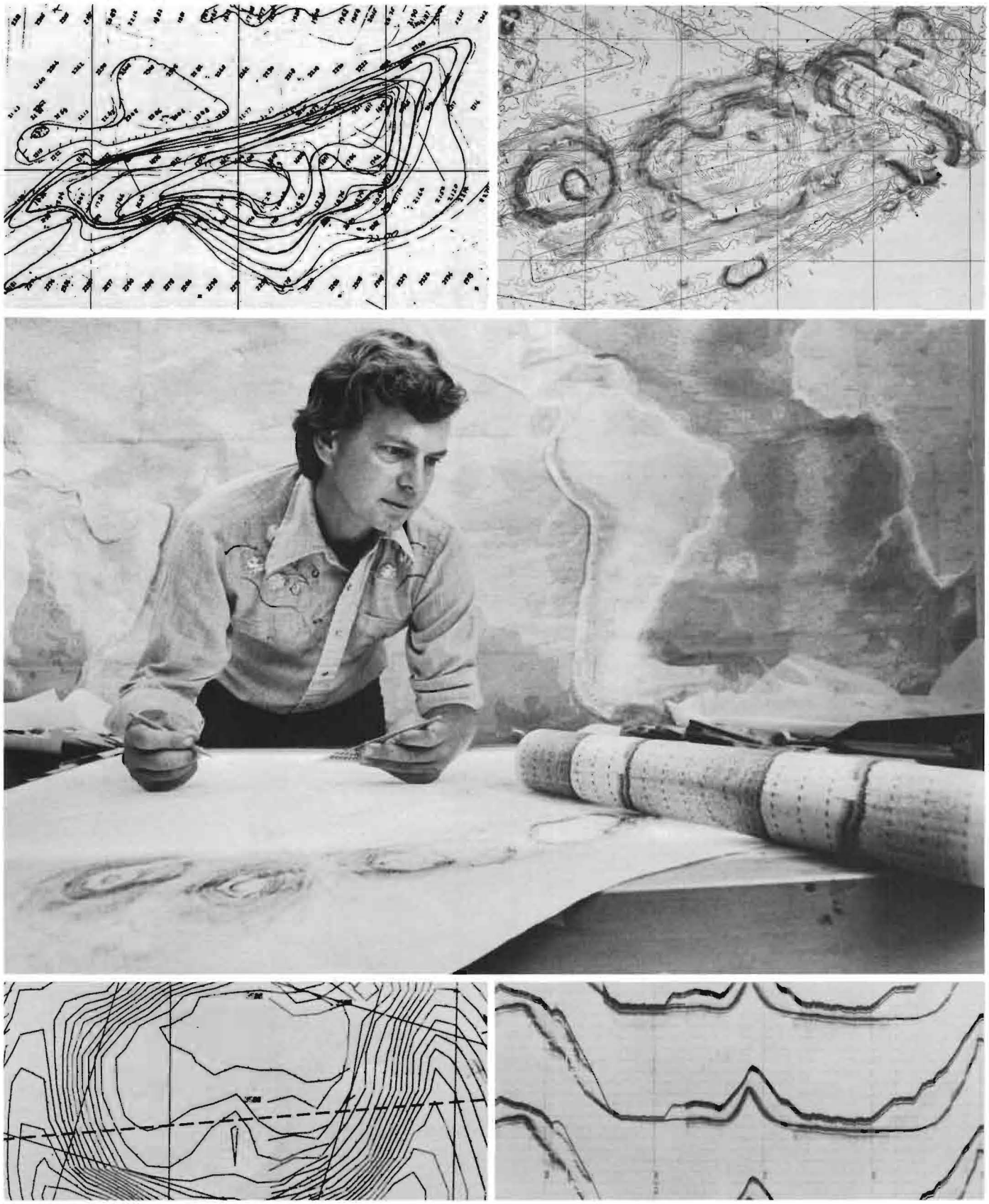
Away from the tectonically active plate boundaries, we use Sea Beam mainly for structural studies of volcanoes (seamounts) and the so-called "plate fabric." Only a few of the hundreds of thousands of volcanic cones on the Pacific floor had been mapped with techniques precise enough to show craters, parasitic cones, eruptive fissures, and faults. These features' presence and pattern must be determined before the styles of eruption and internal structures can be deduced. Even the overall shape and slope angles of volcanoes were poorly displayed on conventional fathograms. The number of adequately surveyed seamounts has been rapidly increased by incidental Sea Beam transits, and by purposeful surveys on the East Pacific Rise flank and off southern California. Some surprising discoveries include the abundance of calderas and nested pit craters, the variety of eruptive fissure patterns, and the dominance of truncated, steep-sided cones rather than gently sloping shield volcanoes. Recognizing patterns of volcanoes—as satellite rings around large cones, in linear chains parallel and oblique to the motion of the oceanic plates, and in special settings such as the fracture zones produced by offsets of the spreading center—is important for determining the cause and timing of eruptions.

The most striking and ubiquitous patterns that Sea Beam has mapped are from the pervasive, lineated, fault-block topography once known as abyssal hills and now more often referred to as the plate fabric. The long, linear faults that produce this terrain begin in very young crust near the spreading center, and extend at right angles to the spreading direction. Mapping the patterns preserved on older crust usually fixes the orientation and arrangements of spreading centers at the time of crustal creation. Thus, Sea Beam maps can be used for regional tectonic reconstructions just as maps of magnetic lineations (which also parallel former spreading centers) have been used in the past. The new technique is most valuable at low latitudes where magnetic anomalies are weak and unmappable, and in areas where the tectonic jigsaw puzzle is unusually complicated by readjustments and realignments of spreading centers. Sea Beam data are also being used for numerical description of the roughness and lineation of the plate fabric, and in the search for quantitive relationships between these parameters and geologic factors like crustal age and spreading rate.

Most of the participants in this first phase of Sea Beam operation are now saturated with data, buried in contour charts, and busy with writing reports—and proposals for further field work, since initial results have only whetted our appetites for learning about the shape of the deep sea floor.

H. W. MENARD

L. D. FORD



Top left: A chain of small seamounts 400 km southwest of San Diego as roughly contoured after a conventional echo-sounding survey. Top right: The same chain as mapped by Sea Beam in June 1983. Center: Dr. Peter F. Lonsdale compares a Sea Beam chart with topographic profiles collected by Scripps's Deep Tow system. Bottom left: A small section of a Sea Beam chart, with a volcano's crater at a 25-m contour interval. The dashed line indicates the location of a Deep Tow track, whose high-resolution profile (bottom right) reveals more details of the crater.

Prochloron

Many biologists, peering down the microscope at green plant cells, have been struck by the similarity of chloroplasts to small, single-celled algae. Many people have considered the possibility that chloroplasts originally evolved from primitive algal unicells, but good evidence for this hypothesis was lacking. The closest alga to a chloroplast might be a blue-green alga, but the pigments do not correspond sufficiently closely. Blue-greens have only one kind of chlorophyll (type a), and generally produce a blue or red proteinaceous (bilin) pigment; higher plants have two kinds of chlorophyll (types a and b) and lack bilin pigments. A prokaryotic alga like a blue-green, but with pigments like those in higher-order plants, might be a better candidate for the role of ancestral chloroplast. We think we have found such an alga: we call it *Prochloron*.

Eighty years ago an imaginative botanist at the University of Kazan, U.S.S.R., proposed that eukaryotic plant cells arose from two consecutive symbiosis steps. One was the incorporation of bacteriumlike cells as ancestral mitochondria, the other was the incorporation of prokaryotic algae as ancestral chloroplasts. This symbiogenesis theory (Mereshkovsky 1905) was published first in Russian and then in German. Few biologists took its message seriously because no testing methods existed for so wild a hypothesis.

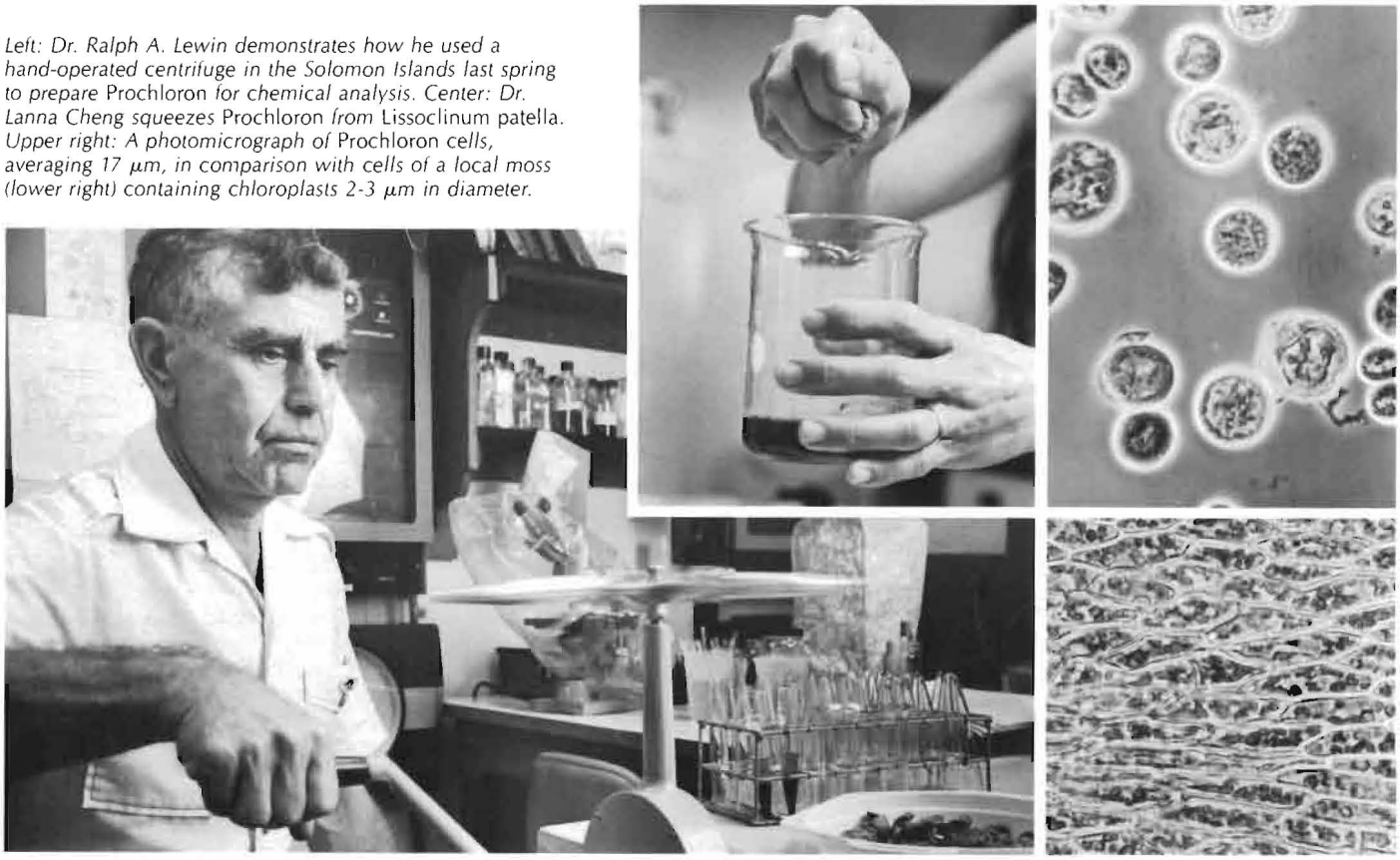
New approaches to the problem are now available—electron microscopy, chromatography, electrophoresis, and other methods for separating and analyzing the molecular components of proteins and nucleic acids. So, ten years ago, when Dr. Lynn Margulis resurrected the theory of symbiogenesis, she was able to marshall so much evidence in its favor that the theory received fairly wide (though by no means unanimous) acceptance. But still there remained the problem of that missing link: the green prokaryotic alga, the postulated ancestral chloroplast.

When I (Dr. Ralph A. Lewin) and Dr. Lanna Cheng found cells that answered somewhat to this description (they have pigments like those of a green plant, but lack a clearly defined nucleus) growing in a thin film on marine invertebrates (didemnid ascidians) at Puerto Peñasco and on other shores in the Gulf of California, we hesitated to accept the evidence. According to all the textbooks, all prokaryotic algae were supposed to be blue-green (i.e. Cyanophytes). When we checked the fine-structure of these green cells by examining thin sections under the electron microscope, we confirmed that they were indeed prokaryotes. After carefully collecting a few milligrams, extracting the pigments, and analyzing them by chromatography and spectrophotometry, we found that they comprised chlorophylls a and b, as in green plants, and no blue or red bilin pigments. Finally we decided to put the algae into a new class, the Prochlorophyta, based on a new genus that we called *Prochloron*.

Over the past decade prochlorophytes have been found in a number of different didemnids on the Great Barrier Reef, and in other locations including the western Pacific. Though we still do not know how to grow them in the laboratory, these odd algal cells have been analyzed by scientists in several countries, using a variety of sophisticated techniques. We have been able to survey different tropical shores and collect different didemnid hosts to see which will most easily yield gram quantities of *Prochloron* cells. By far the best source for clean preparations of *Prochloron* is a colonial ascidian, the protochordate *Lissoclinum patella*, found in shallow water on the coasts of Palau and other coral-reef areas in the tropical western Pacific.

Scientists may never know for sure whether ancestral prochlorophytes gave rise to green plant chloroplasts, but we'll certainly know a lot more about *Prochloron* in the next few years. What this will ultimately tell us about the fundamental nature of green plants—on which we all depend for food, timber, and other necessities of life—remains to be seen.

Left: Dr. Ralph A. Lewin demonstrates how he used a hand-operated centrifuge in the Solomon Islands last spring to prepare Prochloron *for chemical analysis. Center: Dr. Lanna Cheng squeezes* Prochloron *from* Lissoclinum patella. *Upper right: A photomicrograph of* Prochloron *cells, averaging 17 μm, in comparison with cells of a local moss (lower right) containing chloroplasts 2-3 μm in diameter.*



L.D. FORD

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.

OCEAN RESEARCH DIVISION

The Ocean Research Division (ORD) encompasses research of many individual investigators in marine biology, marine chemistry, physical oceanography, and climatology. In this section only a few programs will be discussed. Other ORD programs are mentioned throughout this report; the Marine Natural Products Chemistry Program is highlighted; and the Physical and Chemical Oceanographic Data Facility is discussed in the Shore Facilities and Special Collections section.

The El Niño phenomenon of 1983 was the focus of work for many scientists in both the Climate Research Group and the Volunteer Observing Ship Program. El Niño is a climatological event that occurs every two to seven years in the tropical ocean/atmosphere system and is associated with warmer-than-normal equatorial surface temperature and a weakening of the trade wind system. It is during El Niño that the connection between changes in weather patterns of mid-latitude regions, particularly of the United States, and temperature of the tropical Pacific Ocean is most dramatic.

Climate Research Group

Dr. Tim P. Barnett is investigating the monsoon and Pacific trade wind systems. He identified the precursor for El Niño events as a forced Kelvin wave in the atmosphere. The wave originates over the Indian Ocean and Indonesian maritime continent. The generation of this wave seems to be at the heart of the entire El Niño/Southern Oscillation phenomenon.

Dr. John O. Roads, left, and Dr. John D. Horel at work on the new VAX 11/750 computer shared by the Climate Research Group and the CO_2 Group.

Additional investigations suggest that other propagating wave features originating in the Indian Ocean area trigger the large-scale pressure redistributions in the Southern Hemisphere that are called the Southern Oscillation.

In his global sea-level research, Dr. Barnett studied the long-term change in the density structure of the upper ocean. The observed change in sea level cannot be explained by the warming of the oceans. The most likely cause still appears to be melting of the polar caps.

Dr. John D. Horel investigated the temporal and spatial characteristics of persistent atmospheric circulation patterns. He identified and diagnosed 5-to-20-day periods during which the atmosphere exhibited greater potential for successful medium-range weather forecasts. Most of the persistent episodes are apparently associated with planetary-scale fluctuations in the atmosphere. Dr. Horel is also analyzing the atmospheric and oceanic fluctuations during 1982-1983 associated with the El Niño/Southern Oscillation phenomenon. Dr. Horel, in collaboration with Dr. Barnett, investigated a relatively new technique for analyzing large geophysical data sets. Complex principal components and their linear transformations were used to identify traveling and standing waves in the tropical wind field.

Dr. Jerome Namias and his group continue study of the large-scale air-sea interactions resulting in short-term climatic fluctuations. A monthly data set of sea-surface temperatures (SSTs) for the North Atlantic led to an objective method relating atmospheric average wind patterns to the SST pattern. These specifications, along with those from the North Pacific, are useful in seasonal weather predictions for the United States mainland.

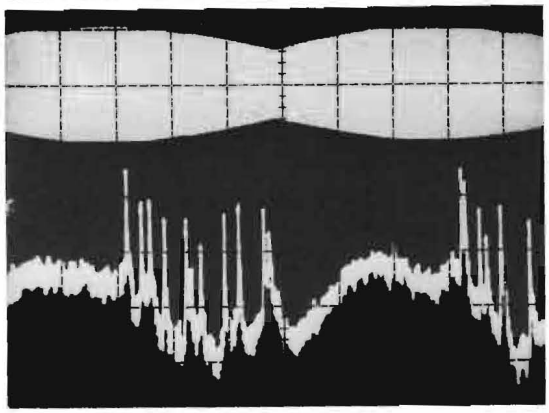
Studies of the extraordinary 1983 El Niño showed that strong upper-level winds over the North Pacific subtropics during winter and spring of 1983 were indicated from the antecedent fall SST patterns, thereby leading to good winter precipitation forecasts for much of the United States. Other research showed that recent decadal fluctuations of wind and weather patterns affecting the United States were related to North Pacific air-sea interactions.

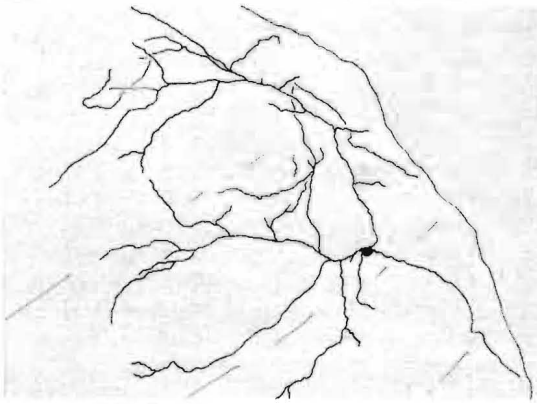
Drs. John O. Roads, Geoffrey K. Vallis, and graduate student Lorraine A. Remer investigated the theoretical relationships between large-scale circulation patterns and cloud fields. Remer and Dr. Richard C. J. Somerville also developed a radiative-convective equilibrium numerical model of the atmosphere for investigating the climatic influence of air-sea interactions and cloud feedbacks. Drs. Roads and Somerville studied atmospheric predictability, using real-date numerical weather forecasts with an idealized linear theoretical model. They found that spurious westward propagation of planetary waves could be caused by incorrect treatments of the influences of mountains and stationary thermal forcing.

Volunteer Observing Ship Program

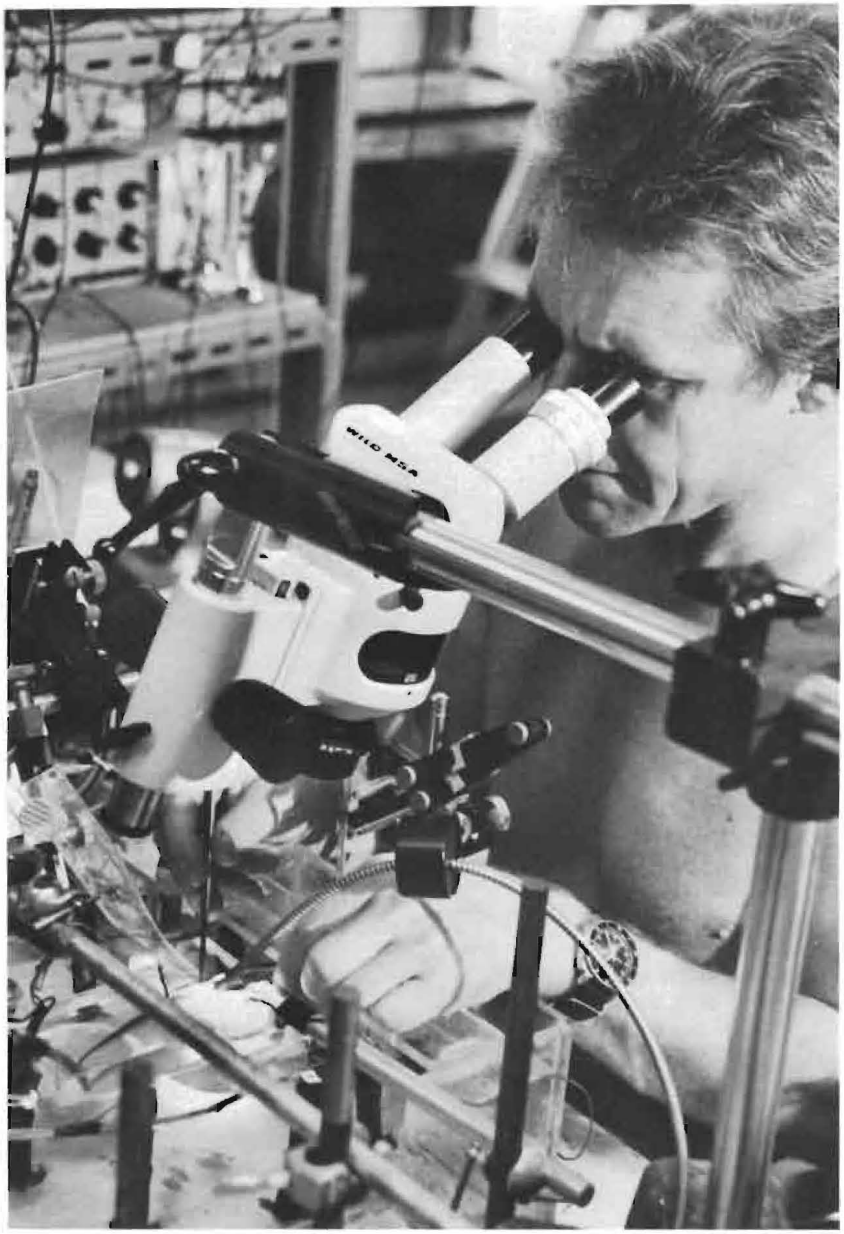
Scripps now coordinates a trans-Pacific fleet of more than 30 merchant ships in addition to its regular research fleet. The merchant ships voluntarily make oceanographic observations over the Pacific Ocean. A combination of data from these vessels, research vessels, and naval operations yields regular temperature measurements for a large part of the tropical Pacific. The fourth year of operation of this data network was blessed by an episode of El Niño, which matured into a climatic event of historic proportions. Although the data analysis is barely under way, it is clear that the temperature network has provided a unique and valuable set of observations. These observations, obtained once or twice a month at several longitudes, will allow a detailed description of the space/time evolution of the temperature field before, during, and after El Niño.

Upper left: A weakly electric fish, Eigenmannia virescens. *Upper middle left: An intracellular recording (lower trace) of a neuron, which fires in response to decreasing stimulus amplitude (upper trace). Lower middle left: Grace G. Kennedy prepares fish brain sections for histological analysis. Bottom left: Camera lucida tracing of intracellularly labeled neuron. Right: Dr. Walter F. Heiligenberg readies the brain of an anesthetized fish for intracellular recording of neurons.*





W. H. HEILIGENBERG



L. D. FORD

The TRANSPAC Volunteer Observing Ship Program started nearly ten years ago during the NORPAX Scientific Program. NORPAX was dedicated to the study of very large pools of unusually cool or warm water in the mid-Pacific and these pools' possible influence on weather and climate. Early in NORPAX it was decided that the most cost-effective way to measure upper-ocean temperatures over wide areas for long time periods was to deploy expendable bathythermographs from merchant ships sailing along their regular trade routes.

Expendable bathythermographs (XBTs) are small torpedo-shaped projectiles. They are thrown from ships and record temperature as they sink through 500-1000 m of water. The temperature data is fed back to the ship through a fine wire. Besides temperature/depth data, some merchant ships take

surface-water salinity samples, plankton samples, and air samples.

Scripps's Volunteer Observing Ship Program is operated by the VOS Group in close association with similar national and international groups. XBT data from these programs are exchanged through the Global Telecommunications System—the same system that handles the world's weather observations.

During 1982 Scripps and Oregon State University cooperated to develop the first satellite-based system for automatically transmitting XBT data on a real-time basis from ship to shore. The data and position information are monitored by France's ARGOS System aboard the United States' NOAA-6 and NOAA-7 satellites. The data are processed in Tolouse, France, and made available on U.S. telephone lines within a few hours after the XBT is dropped.

The temperature/depth data collected by the TRANSPAC XBT Program, and the temperature maps produced from the data, are used in a variety of projects concerned with the formation processes of large-scale (1000-km and year-to-year) and mesoscale (100-1000-km and season-to-season) variability in the upper ocean. Dr. Warren B. White is studying the wind-driven processes generating baroclinic long (Rossby) waves in the eastern mid-latitude North Pacific, and the effects of bottom bathymetry on the quasi-stationary baroclinic waves in the Kuroshio Extension. Both he and Dr. Gary A. Meyers are investigating the large-scale redistribution of mass in the tropical Pacific during the El Niño phenomenon.

Marine Physics

One source of noise in seismic measurements is an oscillation found worldwide with a period of 6-7 seconds. This noise was identified 30 years ago as the result of nonlinear interference between trains of ocean surface waves. When two wave trains are traveling in diametrically opposite directions but have the same wavelengths, there is a small but horizontally extensive pressure fluctuation generated by nonlinearities. It oscillates at twice the frequency of the surface waves. In deep water the pressure fluctuation couples energy into the acoustic field in the ocean and also shakes the seabed, thus generating microseisms that travel worldwide.

In February 1983, observations carried out by Drs. Charles S. Cox and Alan D. Chave and graduate student Spahr C. Webb showed pressure fluctuations and associated electromagnetic fields on the seabed 145 km southwest of San Diego. The period of observation coincided with the passage of a sharp meteorological front during which the surface wind suddenly changed direction by 90° and increased in intensity. This produced wind waves running in various directions; some of these waves were opposed to the oncoming waves generated by the earlier wind. The result was an observable peak on the pressure and electric spectra at the seabed. The spectral peak intensified and moved toward lower frequencies as the fetch and duration of the enhanced wind continued to blow following the frontal passage.

After this process had continued for several hours, the spectral peak moved to such a low frequency that it coalesced with a stationary low-frequency spectral peak. By this time the energy encompassed by this peak had increased by a factor of a thousand or more.

The existence of three unchanging lower-frequency peaks in the spectrum is correlated with observations of sea-surface swell (of half the frequencies of the pressure oscillations). The swell was observed at shore stations and at Begg Rock in the open sea. Presumably, the swell was able to generate opposed wave trains by reflecting off islands and the rugged coastline downswell from the observing point, thereby producing double-frequency oscillations at the seabed.

The observations have several important consequences for understanding the spectrum of low-frequency acoustic noise in the sea. An accounting is possible for all the observed noise in the frequency band between 0.1 and 2.0 Hz in terms of the nonlinear interference of surface waves. At the higher frequencies in this band, even a steady wind appears able to generate a wide enough fan of wave directions to produce oppositely directed wave trains. At low frequencies where only well-defined swell trains from distant storms are present, the reflection mechanism from shorelines may suffice for producing the nonlinear interference.

Below the frequency of 0.1 Hz, the pressure spectrum drops precipitously to a background level that may be associated with ultra-low-frequency acoustic disturbances in the atmosphere. The absence of pressure spectral peaks at the frequency of the swell itself, rather than the double frequency shown by this observation, implies that any direct action of waves (for example as they shake the shores of islands and the mainland) does not send observable microseisms to this oceanic station.

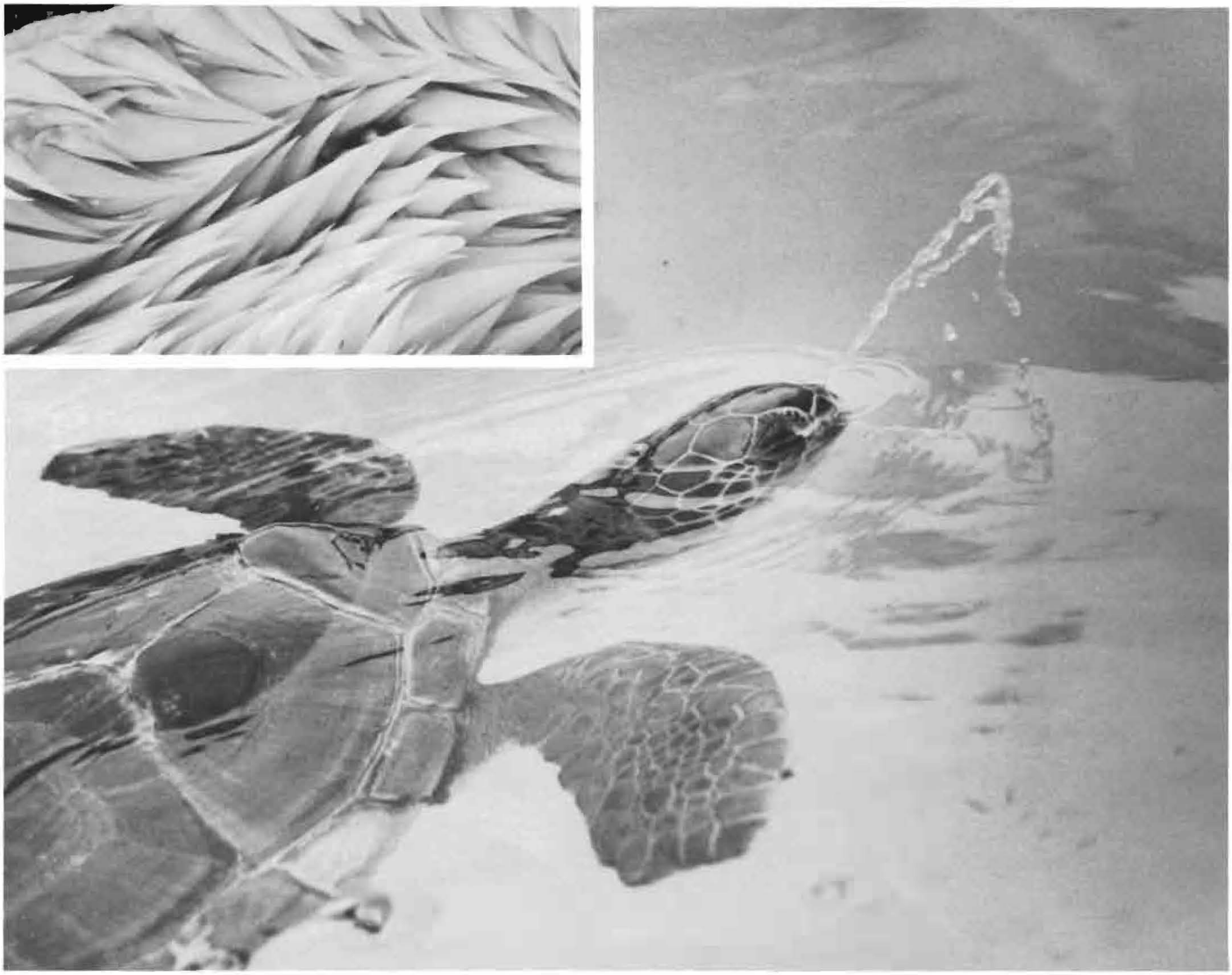
The electric oscillations owe their existence to the relative motions between the water and the sea floor through the geomagnetic field. The electric detector, lying as it does on the sea floor, partakes of any motion of the sea floor. Consequently, relative motion between water and sea floor produces an electromotive force in the antenna of the electric detector.

Neurobiological Research

Influences of steroids on electroreceptor tuning in weakly electric fish are being investigated by Drs. J. Harlan Meyer, Walter F. Heiligenberg, and Harold H. Zakon. Weakly electric fish emit electric-organ discharges (EODs) that are detected by modified lateral-line hair cells (electroreceptors) and used in both communication and location of objects (electrolocation). There are two categories of EODs emitted by weakly electric fish: brief, pulse-type discharges that are emitted at irregular intervals; and quasi-sinusoidal wave-type discharges that are continually emitted at highly regular frequencies. Wave-type discharge frequencies vary not only between species but also within species. Thus, conspecifics in a given locality will most often discharge at separate frequencies. These differences in frequencies are reflected in differences in receptor tuning: electroreceptors of individual animals are most sensitive to the frequency of each animal's own EOD.

To explore the underlying causes of the match between each animal's discharge frequency and the tuning characteristics of that animal's electroreceptors, researchers injected the androgen 5α-DHT, a compound that elicits discharge frequency decreases, into the South American fish *Sternopygus dariensis*. During the course of the hormone treatments, discharge frequencies of the fish were monitored, as were the tuning properties of their electroreceptors. Tuning properties were determined both by impulse-induced receptor oscillations and by single unit recordings. Single unit recordings and EOD frequency recordings from two fish during the course of DHT treatment show that over a one-week period, both fish decreased not only their discharge frequencies but also their receptor "best frequencies" (i.e., the frequency to which the receptor is most sensitive). Such plasticity allows each animal to be maximally sensitive to its own discharge, despite ontogenetic changes in discharge frequencies that have been noted to occur in *Sternopygus*. By being maximally sensitive to the frequency of its own discharge, an animal is better able to utilize its EOD for electrolocation.

Current experiments indicate that the plasticity in electroreceptor tuning is not a direct consequence of the administered androgen, but rather appears to result from the altered frequency of the electric field associated with the EOD. The influences of electric fields upon receptor tuning are being explored in the hopes of better understanding the mechanisms by which electroreceptors are tuned.



F. N. WHITE

Top: The esophagus and stomach of a sea turtle. The esophageal spines (middle left) serve to retain food when the esophagus contracts to expel seawater. A series of pumping cycles propels food to the stomach and forces the water out through the nostrils (below). The system functions in a manner similar to the baleen of whales and minimizes saltwater ingestion when food is swallowed.

PHYSIOLOGICAL RESEARCH LABORATORY

Scientists in the Physiological Research Laboratory concentrate on the physiological and biochemical adaptations of aquatic and terrestrial animals. The biology of free-ranging aquatic birds and mammals is the focus of Dr. Gerald L. Kooyman's group. Field studies were completed by the group on foraging and nurturing behavior of female Peruvian fur seals, in collaboration with West German and Peruvian scientists. This study, held during an El Niño condition, showed there was widespread mortality to both fur seals and sea lions, which appears related to the unavailability of food.

A marine bird receiving an intravenous infusion of 1 mol NaCl/kg H_2O at 0.4 $ml \cdot min^{-1}$ will secrete the salt from its nasal salt glands at the same rate and concentration. Dr. Harold T. Hammel and James E. Maggert find that including the naturally occurring hormone angiotensin II with the infusate at the rate of 10^{10} $mol \cdot min^{-1} \cdot kg^{-1}$ fully inhibits the secretion during the period of the infusion. This rate of infusion is well below the minimum rate affecting heart rate and blood pressure. However, it does cause a measurable increase in amount of NaCl eliminated by the kidneys. The amount of salt infused in 90 minutes will be secreted by the salt glands immediately after the infusion containing angiotensin II is discontinued. These results suggest that angiotensin may be involved in controlling the rate of salt-gland secretion in marine birds.

Most mammals regulate their body temperature within a narrow range by central integration of input from temperature receptors located in the skin, body core, and within the central nervous system. Dr. Martha E. Heath is investigating the contribution of these sites in driving the heat production response in the rat. The contribution of extrahypothalamic core temperature receptors exceeds that of either the skin receptors or receptors in the hypothalamus. Dr. Heath also noted that input from the skin serves to increase the sensitivity to changes in the hypothalamic and extrahypothalamic core temperature, which indicates that the nature of the input from the skin is quite different from that of the body core.

Dr. Edvard A. Hemmingsen is studying the formation of bubbles in cells and organisms under conditions of gas supersaturation in order to better understand the early etiology of decompression sickness.

Dr. Jeffrey B. Graham and his colleagues investigated the function of the pericardioperitoneal canal, a structure unique to sharks and rays. These primitive fishes depend upon the maintenance of a negative pericardial pressure to ensure cardiac filling by aspiration. The canal provides a route for the ejection of fluid into the peritoneum and permits adjustments in pericardial operating pressure and volume. The system may represent a mechanism for control of heart volume and output in these fishes.

Studies in the laboratory of Dr. Fred N. White are concerned with the cardiorespiratory physiology of lower animals and its relationship to temperature and metabolism. Dr. White and associates demonstrated the presence of a circadian rhythm in which CO_2 is retained during the resting phase of the diurnal cycle. The CO_2 (or its influence of pH) is responsible for a significant reduction in metabolism during rest. Dr. Philip E. Bickler demonstrated that this "acidic" phase of the activity-rest cycle is also accompanied by an intracellular acidosis.

A cooperative investigation between Dr. White and colleagues at the UC San Diego School of Medicine revealed that the hypothermic mammalian heart remains more electrically stable when the acidity of the blood is maintained at a more alkaline level than classically sustained during hypothermic human surgery.

Dr. White and graduate student Giuseppe N. di Sciara have noted the presence of long fingerlike projections in the esophagus of several species of sea turtles. The tips of the papillae are oriented toward the stomach. Studies of esophageal pressure of sea turtles during swallowing of food demonstrated that swallowing is powered by a hydraulic pump; when the esophagus relaxes, seawater is taken into the mouth and propels the food into the esophagus, where it is retained by the papillae. Several pumping cycles move the food toward the stomach. Following each ingestion of a bolus of seawater, a strong contraction of the esophagus expells the water; however, the food progressively moves to the stomach. The result is separation of food from seawater. (Ingestion of seawater in large quantities may be fatal to these reptiles.) The adaptation is similar in function to the baleen of whales.

The research of Dr. A. Aristides Yayanos focuses on high-pressure and radiation biophysics. The role of hydrostatic pressure as an ecological factor was investigated in deep-sea bacteria. The rate of reproduction of such bacteria, studied over the range of atmospheric pressures to 1,200 atm, was accelerated at pressures slightly less than the pressures at which the organisms originated. Deep-sea bacteria, when kept at the preferred pressure, exhibit ultrastructural characteristics similar to other bacteria. However, graduate student Roger A. Chastain found a strain from the Marianas Trench that dies at atmospheric pressure and exhibits profound degenerative morphological changes in the process of death. Other studies confirmed that bacteria from the cold deep ocean are strictly adapted to low temperature and are more so the greater the depth of habitation.

Dr. Yayanos also investigated the cause of the Cretaceous-Tertiary mass extinctions, proposing that thermal neutrons irradiated seawater, fresh water, and the plants on the surface of the earth. Such irradiation would have killed many organisms; however, the selective formation of radioactive calcium, sulfur, and phosphorus in the environment appears to be of greater significance. Organisms incorporating radioactive calcium from the environment would thus be irradiated. This hypothesis seems to explain how marine organisms were more susceptible to extinction than those living in fresh water; and how organisms making silicates (e.g., radiolarians) were spared, compared to those making calcite (e.g., coccolithophores). Thus the hypothesis indicates how the patterns in the extinctions occurred.

VISIBILITY LABORATORY

Research at the Visibility Laboratory includes studies of the oceanic and atmospheric optical environment, digital image processing, and optical remote sensing of the oceans.

The spectral nature of the reflectance and attenuation properties of ocean waters were the focus of several major field expeditions. On these cruises Gerald D. Edwards and Jeffrey W. Nolten measured vertical profiles of the downwelling and upwelling natural light fields in the upper 200 m of the water column. From these measurements the depth dependence of the spectral attenuation properties of natural daylight, together with the spectral reflectance of the surface waters, was determined. These studies, under the direction of Roswell W. Austin, support a variety of research programs in remote sensing of the oceans, optical communications, and modeling of image and radiative propagation.

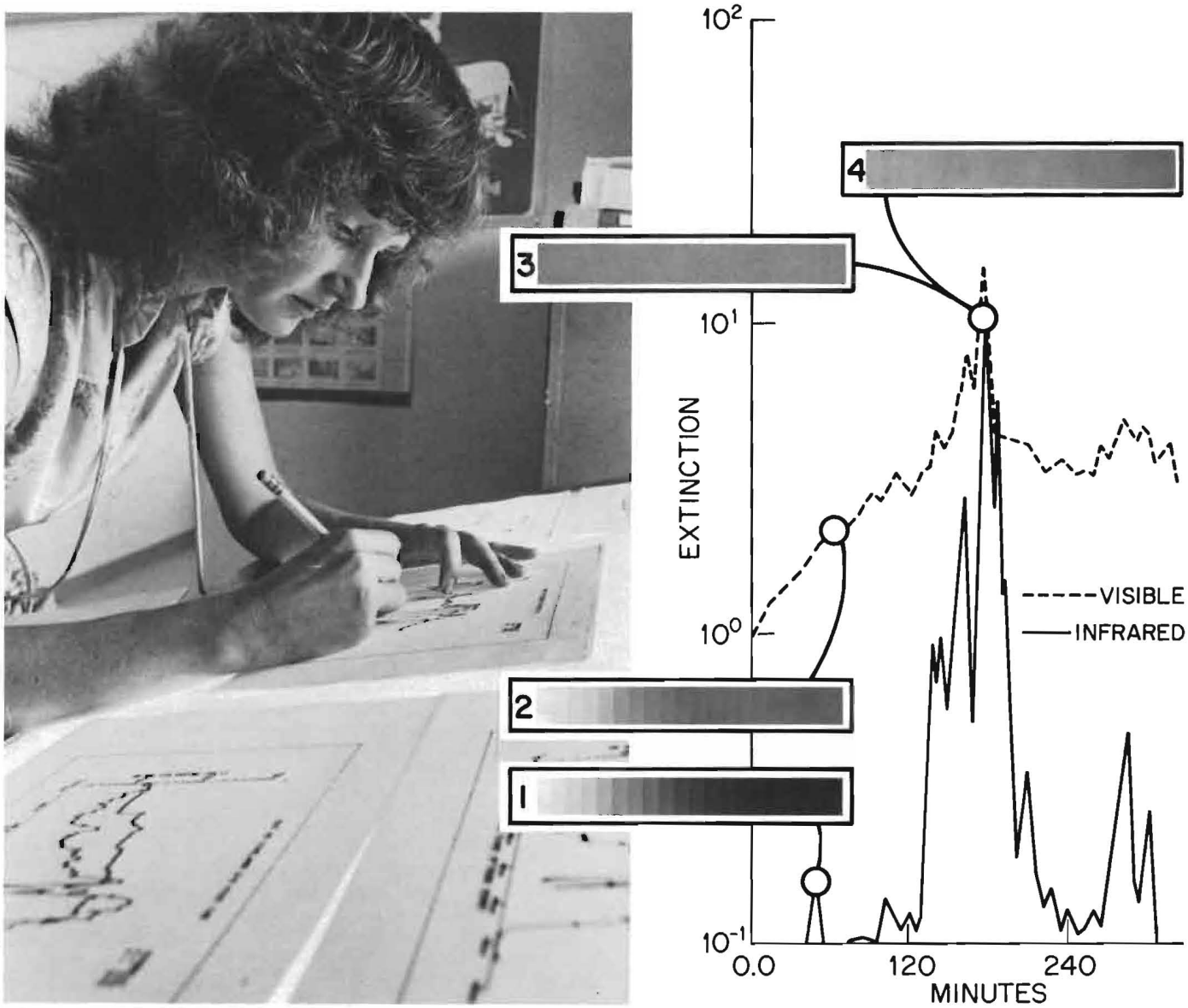
Benjamin L. McGlamery continued his studies and computer simulations of compensated imaging systems. The performance of these sophisticated adaptive optical systems in correcting wavefront distortion induced by atmospheric turbulence has been successfully modeled on the laboratory's Image Processing Computer System. The effect of system modifications and the effect of various subsystems' failure can be rapidly and inexpensively examined.

Richard W. Johnson's research team continued a program of model development and validation studies for predicting atmospheric effects on the propagation of visible and infrared radiation through the lower troposphere. Several aspects of the program changed during the past year as interest in the driving meteorological condition tends toward the analysis of shorter time intervals.

In keeping with this concern for short-term phenomena, the Hering Contrast Transmittance Model was extended into the regime of turbid and cloudy atmospheres. The inclusion of both the relatively uniform full overcast sky and the much more difficult fractional cloud situation markedly enhanced this computationally fast model's ability to assess real-world variabilities. To enhance the model's applicability to realistic visual search methodologies, Wayne S. Hering added visual performance algorithms to the computational procedures addressing variabilities in the observer's threshold contrast, the visual target size, and observer glimpse times in combination with the atmospheric factors.

Dr. Bruce W. Fitch's analysis of aerosol size distributions also shifted toward the study of variations occurring over relatively short time intervals. His analysis of an extensive ground-based and airborne measurement set clearly identifies three highly recurrent volume (mass) mode size distributions in the radius range 0.2-6.0 micrometers. However, there is inadequate temporal resolution in the data to address modal short-term behavior. Current studies of an auxiliary, 3-month data set, containing measurements taken at 30-minute intervals, will be applied to this problem, and should lead to a more rigorous specification of modal behaviors and their probable origin.

An extensive set of hourly measurements of visible and infrared extinction coefficients analyzed by Janet E. Shields led to a recognition of the need for finer temporal resolutions. Consequently, the current analysis has shifted to a data set in which extinctions in the visible, 3-5μm and 10-12μm bands were measured at 1-minute intervals, for 1 year. Analysis of these data, concentrating upon intervals containing heavy haze,



L. D. FORD

The extinction of visible and infrared radiation by tropospheric aerosols during the onset of heavy mist or fog is a highly dynamic phenomenon. At left, Janet E. Shields analyzes simultaneously measured extinctions plotted at one-minute intervals as a prelude to predictive model development. Right: The temporal variations in visible and infrared extinctions before and during a moderate fog episode are illustrated in this sample plot. Note the nonlinear relationships between the data in the two spectral bands. The simulated loss in image transmission quality is illustrated by inset gray scales. High extinction with its concomitant poor image quality at points 3 and 4 is contrasted with the low infrared extinction and good image quality at point 1, and the simultaneous moderate visible extinction and intermediate image quality at point 2.

mist, and fog, is being used to identify the conditional probabilities linking the continuance of high infrared (IR) extinctions with a variety of precedent visible and IR thresholds.

The development of specialized radiometric instrumentation to support these studies in atmospheric effects has slowed. However, a new compact multichannel nephelometer suitable for both ground-based and airborne applications is near completion, as is a miniature, solid-state scanning radiometer for measuring full-hemisphere radiance distributions. These systems, when fully operational, will allow real-time validations of many of the predictive relationships emerging from the studies outlined above.

CENTER FOR COASTAL STUDIES

The Center for Coastal Studies serves as an organizational focus for Scripps's research in coastal dynamics. The center includes the Shore Processes Study Group, Scripps Hydraulics Facility, and the Marine Archaeology Program. Scientists at the center concentrate on field experiments and supporting analytical and model studies to unravel the complex interactions of waves, currents, and winds with the sedimentary boundaries of the ocean.

The widespread damage to the coastlines of California and the nation during recent severe winter storms has sharpened the urgency for applying the center's basic research results. Requests for service to public and private agencies concerned with coastal erosion have increased rapidly. Dr. Douglas L. Inman, director of the center, has conducted a comprehensive study of the long-term erosion in Oceanside, California, with a view toward restoring the beach and preventing further property damage. Dr. Reinhard E. Flick, with Bernard D. Zetler, has helped predict future periods of extreme astronomical tides.

The first phase of studies of wave climate and sand transport and erosion processes in the Nile Littoral Cell (extending from Alexandria, Egypt, to Haifa, Israel) has concluded. Dr. Inman and Robert L. Lowe have been part of a cooperative marine technology program for the Middle East sponsored by the United States Agency for International Development (AID). The work has provided wave-energy and directional estimates from several stations in Egypt and Israel and has clarified the characteristics of waves generated by fast-moving Mediterranean storms, and the effect of those waves on Nile-Delta-derived sediments. The second phase of the AID program will focus on an increased exchange of information between Israeli and Egyptian scientists, and on training them in data analysis techniques.

Drs. Clinton D. Winant and Russ E. Davis continue their work in the four-year-long, multi-institutional Coastal Ocean Dynamics Experiment (CODE). CODE is designed to identify and study the important dynamical processes governing the wind-driven motion of coastal waters. Two field experiments have been carried out between Point Reyes and Point Arena off California. Moored current meter instruments deployed for up to four months recorded such variables as horizontal current motion, bottom pressure, temperature, and density. These measurements were supplemented with drogue studies, hydrographic observations from ships, and meteorological observations from airplanes. In another project, graduate student Kathryn A. Kelly completed a study of satellite images of sea-surface temperature over an area including the CODE region. Although CODE has been concerned mainly with physical oceanographic processes, the participants hope the experiments will provide a framework in which biological, chemical, and geological observations can be made.

D. L. INMAN CENTER FOR COASTAL STUDIES

Beach erosion caused by seawall south of the Scripps Pier, on March 26, 1983

Dr. Robert T. Guza and his students analyzed data of wave elevations and currents in the surf zone. Graduate student Joan Oltman-Shay developed high-resolution spectral estimates to study surf beat—energetic motions with periods of roughly 200 seconds. Graduate student Steven L. Elgar compared observed groupings of high waves with the predictions of linear theory and began developing nonlinear models.

Dr. Steven S. Pawka continued his work on the directional properties of surface gravity waves. He has further developed high-resolution, data-adaptive estimators used to extract directional information from arrays of wave-sensing instruments. These remarkable techniques allow quantitative measurement of the blocking effect of San Clemente Island on waves at Torrey Pines Beach about 100 km shoreward. Dr. Pawka also generalized certain methodologies to cover the optimal estimation of arbitrary spectral moments, such as the radiation stress tensor known to be closely related to longshore sand transport.

Dr. Scott A. Jenkins continues his work on innovative sediment management techniques with development of passive, vortex-generating wings designed to resuspend fine sediment in rivers and adjacent harbor berthing areas. A test array of 7 upwashing and downwashing wings, each 7 m in span and made of fiberglass-coated urethane foam, succeeded in eliminating all sedimentation and dredging near a drydock entrance at California's Mare Island Naval Shipyard. Plans are under way to install vortex foils in a nuclear submarine berth to reduce the bothersome ingestion of silt during dockside testing of the ship.

In a new marginal seas effort, Drs. Winant, Guza, Myrl C. Hendershott, and Nancy A. Bray, in close cooperation with Mexican scientists, initiated study of wind-driven circulation, water-mass generation, and fine-structure in the Gulf of California. As in all marginal seas, the coastal boundaries of the gulf limit the scale and thus simplify measurement of budgets of mass, momentum, heat, and salt. In this project Dr. Winant seeks to determine whether the gulf circulation is coherent across the entire section, or whether oscillations on each shelf are isolated by an "ocean" in between. Dr. Guza is studying the wind-driven current motions in very shallow water; in the gulf these motions are relatively free of surface gravity wave influences. Dr. Hendershott is measuring the generation and decay of fine-structure produced in the intense flow over the shallow sill in the Ballenas Channel. Dr. Bray is concentrating on the water-mass generation and circulation of the northern gulf.

Dr. Patricia M. Masters, Marine Archaeology Program, is studying shifts in the species of mollusc shells excavated from coastal Indian middens dating from 8,000-3,000 years B.P. Changing shoreline environments that evolved by the interaction of coastal dynamics and the final stages of the Holocene sea level rise are indicated by differing proportions of molluscan species found in the middens.

DEEP SEA DRILLING PROJECT

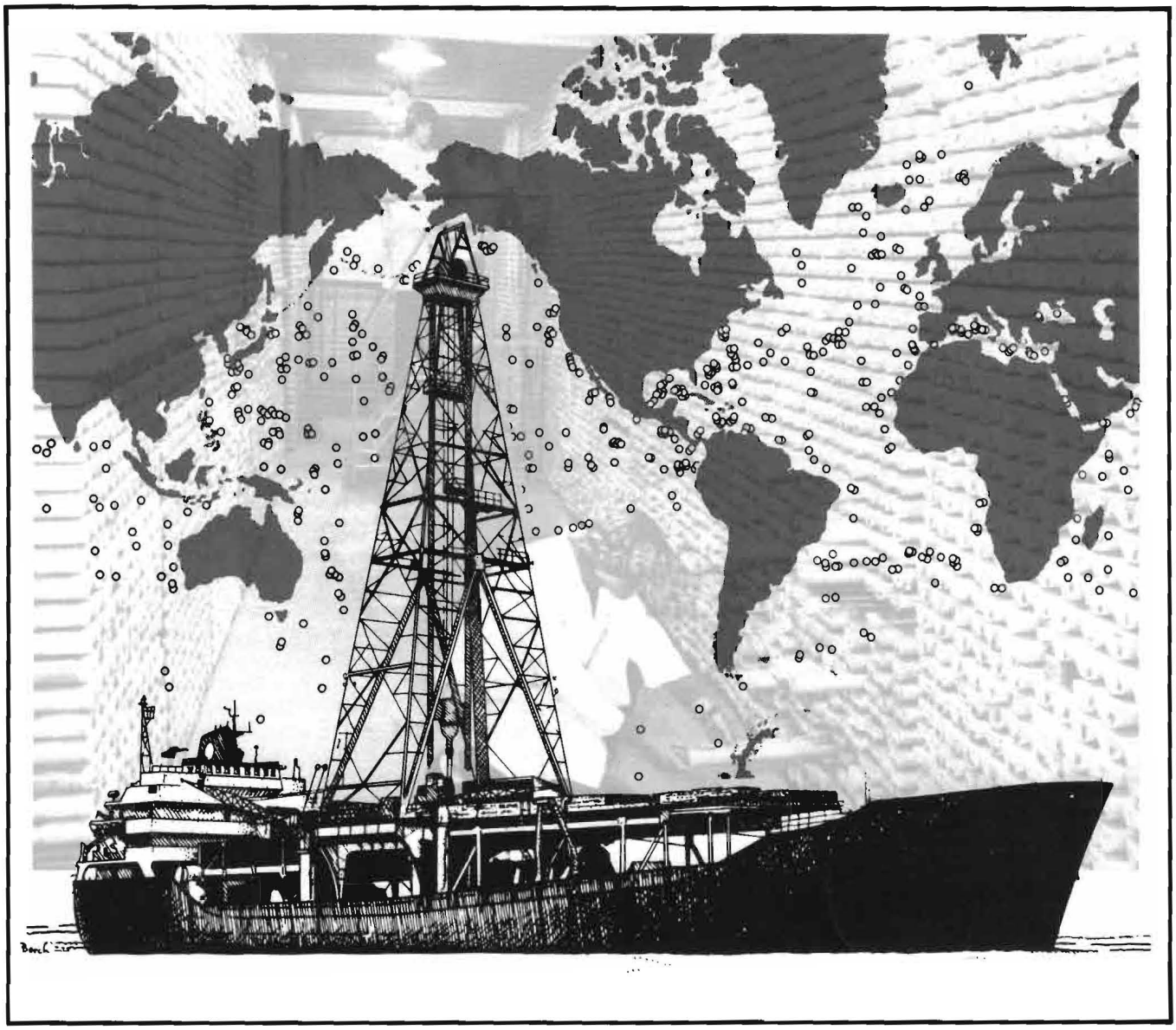
Following more than 15 years of scientific ocean drilling, *Glomar Challenger* will cease Deep Sea Drilling Project operations in November 1983. No single scientific program has had greater impact on the earth sciences. The efforts of the Deep Sea Drilling Project staff and a worldwide scientific community have guided the *Challenger* program to success. This program allowed researchers to view geological processes on a global scale, to test long-held theories through direct sampling of the ocean basins, and to integrate numerous disciplines into unifying concepts.

This past year scientists aboard *Glomar Challenger* carried out an ambitious program in the Pacific. Then *Challenger* and a new research crew returned to the Atlantic to begin the final drilling phase. There were some outstanding results, some surprises, and a few disappointments. An increasing focus of the program has been on multidisciplinary studies of global concepts and events. Major topics were paleoceanography (reconstructing ever-changing worldwide physiographic, climatic, current, and biotic patterns of the oceans), passive and active margins, mid-plate volcanic processes, and the nature of the earth's crust and its circulating hydrothermal fluids.

Cenozoic Environments of the Pacific Ocean

The Cenozoic was a time of global climatic deterioration. Changing ocean-bottom geometry opened passageways altering oceanic circulation and climatic patterns. Cold Antarctic bottom waters moved into the Pacific, creating steep temperature gradients within the water column, and greater temperature variations between high and low latitudes. Biotic responses to changing environments are recorded in Pacific Basin rocks.

A multicruise expedition to study these changing environments yielded excellent data on surface and bottom-water circulation, biotic productivity, and rates of



C. VON DER BORCH DEEP SEA DRILLING PROJECT

Glomar Challenger*'s drilling sites pepper the map of the world's oceans. A worldwide community of scientists has examined 94,000 m of cored rock and sediment from the ocean basins during the Deep Sea Drilling Project's 15-year program of scientific ocean drilling. (Background shows cores stored at the DSDP West Coast Repository.)*

organic evolution from three major areas: the equatorial high-productivity zone (leg 85), the western North Pacific (leg 86), and the southwestern Pacific (legs 89 and 90).

Highlights of this program included: (1) Recovery of an excellent sequence spanning the Tertiary/Cretaceous boundary (Site 577 on the Shatsky Rise). The expanded sequence allows detailed study of this key interval. (2) Recovery of the Eocene/Oligocene transition at Site 574 (equatorial Pacific) and Sites 592 and 593 (southwestern Pacific). The interval marks a significant oceanographic event possibly associated with the formation of the first Antarctic sea ice and the introduction of cold bottom water to the Pacific. (3) Detection and delineation of the southwestern Pacific regional hiatus from coring at Sites 588, 592, and 593. (4) Detection of marked Neogene productivity fluctuations in the southwestern Pacific and recovery of virtually undisturbed shallow-water Neogene sequences from eight sites along a latitudinal transect from the equator to 45° south. (5) Dating the Kaikoura orogeny in New Zealand at six million years. (6) Recovery of undisturbed sections of red clay, presumably with large eolian components, in the western North Pacific (Sites 576, 578, and 581). (7) Correlation of ash horizons recovered at Sites 578 to 580 with seismic reflectors detected over wide areas of the western North Pacific.

Mesozoic Environments/ Mid-Plate Volcanism

Clues to the earliest development of the Pacific Basin are deeply buried in isolated remnants of the old Pacific crust. An ambitious attempt to sample presumed Jurassic crust at Site 585 (leg 89) in the east Mariana Basin failed when unexpectedly high dynamic stresses on the drill pipe precluded setting the reentry cone and penetrating to the necessary depths. Single-bit drilling, however, penetrated to 895 m and confirmed that the basin was already 4 to 5 km deep by Aptian (late early Cretaceous) time.

The leg 89 team encountered vast floods of Cretaceous flow basalts at another site (462A) in the Nauru Basin. The hole, initially drilled during leg 61, was deepened by 140 m. The evidence for intense volcanism during Aptian time in the Nauru and Mariana basins swells the growing body of evidence suggesting widespread and voluminous mid-plate volcanism in the Pacific Basin.

Active-Margin Processes

Converging plate margins are the sites for complex interactions between continental and oceanic crust. Researchers drilled off Japan (leg 87) to determine the relative importance of accretion, tectonic erosion, and downslope transport along actively converging margins. Scientists clearly demonstrated the absence of recent accretionary deposits along the Middle American margin (leg 84). On the other side of the Pacific, the leg 87 team investigated the mechanics of subduction and deformation in the Nankai Trough (especially accretionary processes) and the Japan Trench (tectonic erosion).

Tests of physical properties provided significant indications that the sediments on the landward side of the Nankai Trough were not dewatered or deformed in the manner expected of an accretionary prism: dewatering was similar on both sides of the trench and apparently resulted from loading under trench fill rather than from deformation during subduction.

In contrast, rocks cored from the Japan Trench were tectonically deformed. Numerous dewatering veins and normal and reverse microfaulting strongly suggest that the margin was eroded during subduction and later modified by vertical tectonic processes.

Passive-Margin Processes and Products

As the trailing edge of the drifting North American continent, the eastern seaboard of the United States continues to invite rigorous investigation. Scientists aimed their studies during leg 93 at the reconstruction of development of this classical passive margin. This work enabled earth scientists to (1) learn more of the processes shaping the outer continental shelf and rise, (2) test theories of global sea-level fluctuations through study of regional hiatuses in the stratigraphic record, and (3) produce highly resolved stratigraphic sequences for the western North Atlantic.

Discovery of an extensive deep-sea fan complex in the continental rise off Cape Hatteras (Site 603) has also sparked interest in evaluating the rise as a potential petroleum province. The sequence here has all the necessary lithologic ingredients —caprock, sandstone reservoir, and "black shale" source rock. However, relatively shallow burial has precluded development of mature hydrocarbons. Subjected to a different postdepositional history, such a sequence could produce petroleum.

Crustal Water Circulation

The recent discovery of black smokers—hot water vents on the sea floor—has drawn increased attention to processes and effects of water circulation within the ocean crust. Sea water percolating through porous crustal rock interacts with the rock over long periods of time. The resultant mineral-rich hydrothermal fluid escapes through vents (smokers) in the sea floor in areas of actively forming and spreading crust. Resulting deposits are often rich in valuable minerals.

High interest in the role of crustal water circulation in controlling oceanic chemistry led DSDP scientists to drill 19 holes (Sites 597-602, leg 92) along latitude 19°S on the west flank of the East Pacific Rise. Through direct sampling and pore-water and heat-flow programs, they demonstrated that hydrothermal processes continue in ridge flank environments long after new crust forms. Circulating water is significant in redistributing elements within the crust, controlling chemical balance in the oceans, and producing significant crustal cooling.

A return to Hole 504B, near the Costa Rica Rift, provided more data about fracture patterns and structures that may control the flow of hydrothermal waters. Hole 504B, previously drilled during legs 69, 70, and 83, penetrates over 1000 m into basaltic crust. Tests conducted over the past several years have indicated a substantial flow of water down the hole and into adjacent rock. Data obtained from an oblique seismic experiment conducted at the site will also provide clues to the fracturing density, anisotropy, and velocity structure of the crust.

Solid-Earth Geophysics

The year was marked by increased attention to sophisticated downhole geophysical experiments. Deep-sea drilling technology has made it possible to couple seismic instruments to the ocean crust within boreholes. Relatively free from extraneous noise, ocean-crust systems potentially provide higher quality data than do land-based or ocean-bottom systems.

Near the Tonga Trench the leg 91 team emplaced a sophisticated borehole seismometer that comprises a cylindrical borehole instrument package and a sea-bottom processing package containing data storage and power systems. Because

the diameter of the instrument package is larger than that of the drill string, the package was deployed through the reentry cone attached to the end of the drill string. Data were successfully collected on board ship, but degradation in the sea-bottom processing unit precluded long-term seismic monitoring.

Leg 88 scientists successfully emplaced a borehole seismometer off the Kuriles (Hole 581C) in the seismically active northwestern Pacific. The instrument was deployed through the drill string and clamped 23 m into basement rock. This rare opportunity to monitor earthquakes in an active subduction zone paid double dividends. As planned, the system recorded excellent data for two months. In addition, during the University of Hawaii's operations to retrieve the data package, the system recorded the 7.7 (surface-wave magnitude) May 1983 earthquake off Japan.

Tools

The great success of the Pacific paleoceanography program stemmed directly from the development of the hydraulic piston corer, which can recover undisturbed sediments up to sub-bottom depths of 300 m. DSDP workers developed an advanced piston corer (APC) this past year, and successfully deployed it during leg 94 in the northeastern Atlantic. The new APC is significantly shorter than the earlier version to allow greater ease of handling. It also provides 80% more coring force, creating the potential for piston coring to even greater depths.

Another tool, the extended core barrel, was successfully tested in the southwestern Pacific during leg 90. This core barrel extends several centimeters beyond the core bit, ensuring recovery of rotary-cored sediments that are less disturbed by the action of the bit's main jets. The bottom-hole assembly is designed to accommodate both the hydraulic piston corer and this new rotary coring system. Thus conversion from piston to rotary drilling is now possible without retrieving the drill string.

GEOLOGICAL RESEARCH DIVISION

This year's reports from scientists in the Geological Research Division cover aspects of (1) the physical evolution of oceanic plates from their birth at ridges through their consumption at oceanic trenches, and (2) the earth's chemical history from creation to recent human influence.

Dr. Richard N. Hey and associates made two cruises to continue their research into large-scale and fine-scale plate tectonic evolution. On one cruise they used Sea Beam, magnetics, and the MPL Deep Tow system for a high-resolution study of the "type-example" propagating rift, at 95.5°W along the Galápagos spreading center. This was the first major expedition on which Sea Beam and Deep Tow were used together; the combination is proving valuable in understanding sea floor tectonics. Dr. Hey and graduate student Martin C. Kleinrock are comparing the data with results from a GLORIA long-range side-scan survey of the same area. The new results closely match the pattern predicted by the propagating rift hypothesis, which the researchers conclude can be incorporated into plate tectonic theory.

Dr. Hey's second cruise was a large-scale Sea Beam/magnetics/gravity survey (and dredging) of the anomalous "Easter microplate" area in the southeastern Pacific. Evidence was discovered to strengthen the hypothesis that the eastern segment of the East Pacific Rise (EPR) has propagated north at 500 mm/yr (km/Ma.), and that concomitantly the western spreading segment has slowed, perhaps died, within the past few hundred thousand years. The EPR is in the process of shifting more than 300 km east, toward the Easter hotspot, by the rift propagation mechanism. Dr. Hey and graduate student David F. Naar are analyzing data that seem to show a new type of diffuse sea-floor spreading ahead of the propagator tip.

Dr. Robert L. Fisher, with Dr. John G. Sclater of the Massachusetts Institute of Technology, published the results of the long-term study of the Antarctica/Africa plate boundary and of plate motions/pole stability of the western Indian Ocean since the late Jurassic. Comparable investigations in the southernmost and southeastern Atlantic were initiated. This program underpins and provides context for imminent dredge sampling, employing R/V *Melville*, of plutonic crustal and upper mantle ultramafic and mafic rocks from cross-fractures of the southwesternmost Indian Ocean. Drs. Fisher and Sherman H. Bloomer collaborated on a laboratory study of geophysical data and on geochemical analysis of igneous rocks collected by Dr. Fisher from the three deepest regions of the Pacific (the lower flanks of Challenger Deep of the Marianas Trench, and the Tonga and Philippine Trenches) to determine implications of these characteristics for varying structural evolution and tectonics of these little-sedimented and primarily nonaccreting active margins.

Dr. LeRoy M. Dorman led a successful field study of seismic wave propagation in the western Philippine Sea. The work was motivated by the region's unusual characteristics, including deeper water than predicted by current plate tectonic theory and thinner-than-normal oceanic crust. The experimental plan included observations of seismic waves from explosions recorded by digital ocean-bottom seismographs at ranges up to 500 km parallel to the isochrons, and observations to 60 km at a variety of azimuths to study seismic velocity anisotropy. Initial data shows that the amplitudes of seismic waves do not decay with distance from the source as rapidly as is predicted by current models of sea floor structure.

Dr. James H. Natland and graduate student Elizabeth Wright participated in a month-long field program to evaluate the petrology and tectonic history of the Samoan Islands. The work is part of a cooperative investigation with the University of Hawaii and the University of Newcastle-Upon-Tyne, United Kingdom. The 300 samples, taken for petrologic and paleomagnetic studies from four islands, will be used to evaluate the influence of an undepleted mantle on the compositions of volcanic rocks. Dr. Natland is also comparing Samoan lavas with those from other nearby volcanic chains, and from Cretaceous seamounts of the central and western Pacific, which appear to have had similar mantle sources.

Dr. J. Douglas Macdougall collaborated with graduate students and Dr. Robert C. Finkel to continue studying the chemical properties of the earth's mantle, using uranium and thorium decay series isotopes. Recent volcanic rocks from many tectonic settings, including mid-ocean ridges, island and continental arcs, and oceanic islands, are being investigated. So far, results indicate that this will be a valuable method for investigating mantle characteristics as well as processes occurring during the generation of volcanic rocks.

Scientists in Dr. Edward D. Goldberg's laboratory probed the sedimentary records for evidence of human activity impacting upon the environment. Dr. Daniel O. Suman examined the history of agricultural burning in Panama via the amounts and types of charcoal found in nearby coastal marine sediments. The uniformity of charcoal fluxes over the past few centuries suggests that both the extent of land area burned and the involved vegetation have not significantly changed. Most of the charcoal is transported to the oceans by rivers. There is, however, an increase in recently deposited strata of spherical charcoal particles (cenospheres) produced by oil- and coal-burning ships.

Minoru Koide and Dr. Goldberg found evidence for the dispersion of uranium in the polar region from the aborted Russian satellite, *Cosmos 954*, which burned up on January 24, 1978, over northern Canada. The entry of debris from its

nuclear reactor is indicated by distorted U-234/U-238 ratios in the glacial strata formed after the disaster.

The paleoceanography group—Drs. Wolfgang H. Berger, Robin S. Keir, John S. Killingley, and Edith S. Vincent —investigated mixing processes on the sea floor, the deglaciation event (15,000 to 8,000 years ago), the effects of diagenesis on foraminiferal isotope signals, and Miocene ocean history.

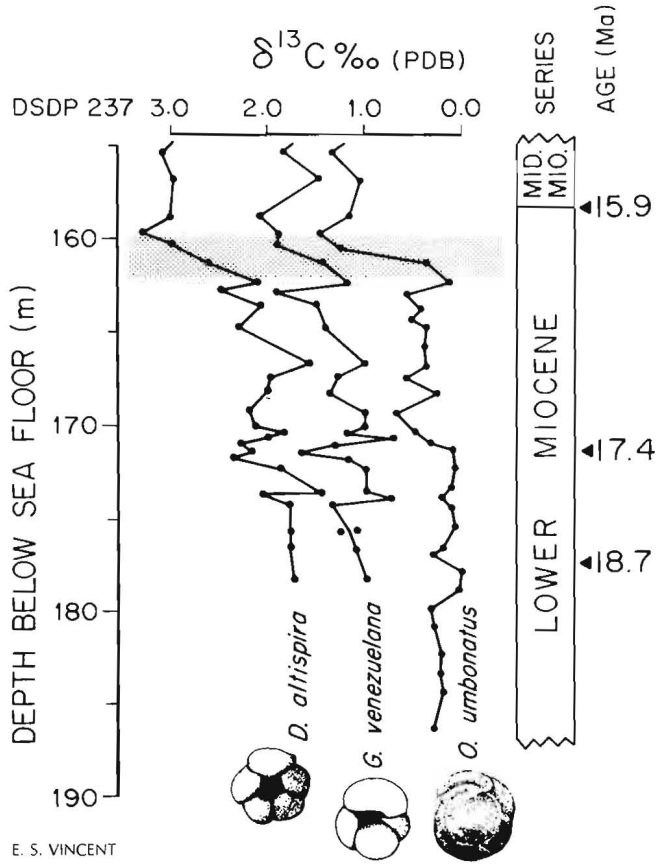
Their careful study of a Sargasso Sea box core (with several radioisotope stratigraphies) revealed that uranium-series isotopes are not useful for specifying the diffusion rate in the Goldberg-Koide mixing model. The isotopes do give clues, however, as to mixing depth, which even in this low-fertility area is about 4 cm beneath the surface. This compares with equivalent previously established depths of between 7 and 12 cm for the western and eastern equatorial Pacific.

An important phenomenon occurring during deglaciation was the pCO_2 (partial pressure of CO_2) rise seen in polar ice cores. A geochemical box model that keeps track of alkalinity and ΣCO_2 (total CO_2) changes in the ocean during deglaciation has been constructed to check the different ways in which pCO_2 can be changed. Two hypotheses are being investigated: the phosphate-extraction model and the coral-reef model. A combination of processes were at work. The distribution of

L. D. FORD

Upper and middle left: Dr. Edith S. Vincent washes a sample of calcareous ooze over a 63-μm-mesh screen. Middle top: She removes the samples from a DSDP core. Bottom left: Dr. Vincent examines microfossils in the sand fraction under the microscope. The microphoto (middle bottom) shows the skeletal remains of planktonic foraminifera, approximately three million years old (Middle Pliocene), from DSDP Site 62 in the western equatorial Pacific. Various species of foraminifera are separated under the microscope, then analyzed with a mass spectrometer for their isotopic composition. This provides clues to the temperature and carbon chemistry of ancient oceans.

A graph shows the $\delta^{13}C$ values for shallow-dwelling planktonic foraminifera (Dentoglobigerina altispira) *as well as deep-dwelling* (Globoquadrina venezuelana) *and benthic species* (Oridorsalis umbonatus) *from DSDP Site 237 in the tropical Indian Ocean. The significance of the abrupt increase in the $\delta^{13}C$ values (stippled area, just below 160 m) is described in the text.*



E. S. VINCENT

benthic foraminifera apparently changed significantly during deglaciation, suggesting important alterations in deep circulation.

Previous interpretations of $\delta^{18}O$ (anomalous ratios of ^{18}O to ^{16}O) records of Cenozoic sediments have been thrown into some doubt. Calculations show that an increased separation of $\delta^{18}O$ values of benthic and planktonic foraminifera, interpreted as bottom-water cooling, can also be accounted for by diagenetic processes. The sizes of the observed and calculated signals are of the same order.

Carbonate fluctuations in the Neogene, and especially major "dissolution spikes," correlate across latitudes for many Pacific regions. Faunal and stable isotope data indicate that the mix of processes (organic carbon injection and extraction, basin-basin fractionation, fertility fluctuations) responsible for the fluctuations varied considerably at different times.

A distinct shift in $\delta^{13}C$ of the ocean (toward heavier values) occurred in the latest Early Miocene, at approximately 16.5 Ma., over a period of about a half-million years. The "Chron-16 Carbon Event" distinctly precedes the ice buildup on Antarctica (15 to 14 Ma.). The researchers propose that the lock-up of carbon in the Monterey Formation (and equivalent deposits) may have produced the ^{13}C event, and also may have reduced atmospheric pCO_2 sufficiently to produce the cooling and ice growth seen in the $\delta^{18}O$ record.

Theoretical calculations show that appreciable changes should occur in atmospheric $\delta^{14}C$ values because of changes in atmospheric pCO_2. Therefore Drs. Devendra Lal and Roger R. Revelle suggest that $\delta^{14}C$ studies on lake sediments should be carried out to delineate pCO_2 changes during the past 50,000

years. The lake $\delta^{14}C$ values should closely reflect the atmospheric $\delta^{14}C$ values, because of rapid exchange of atmospheric CO_2. However, the record of $\delta^{14}C$ would include any effects of changes in the earth's dipolar magnetic field, which alters the global production rate of ^{14}C. Any short-duration, appreciable shifts in atmospheric $\delta^{14}C$ would, however, be caused by changes in pCO_2; long-term shifts could be caused by changes in pCO_2 as well as in the earth's dipolar magnetic field. Accurate studies of lake sediments and polar ice cores will allow the researchers to clearly delineate changes in atmospheric pCO_2 and in the dipolar magnetic field.

The abrupt excursion in $\delta^{14}C$ in Jihyueh T'an (Sun and Moon Lake), Taiwan, sediment at (15-20) x 10^3 yrs B.P. confirms the conclusion of French and Swiss groups (based on studies of Antarctic and Greenland ice cores) that atmospheric pCO_2 was then about 50% lower than at present.

Oceanic and atmospheric distributions of trace gases continue to be the focus of Dr. Ray F. Weiss's research. As part of the Transient Tracers in the Ocean (TTO) program, continuous measurements of surface water and atmospheric carbon dioxide, nitrous oxide, and methane were made in the tropical Atlantic. Distributions of dissolved fluorocarbon-11 and fluorocarbon-12 were also measured during the TTO tropical Atlantic study by graduate students John L. Bullister and Mark J. Warner, and by Frederick A. Van Woy. Similar measurements were made by Bullister on the eighth leg of Benthic Expedition in the eastern tropical Pacific. Because marine concentrations of these man-made gases reflect increasing concentrations in the atmosphere, the compounds provide a new and extremely useful dating technique for the study of subsurface mixing and circulation rates in natural waters.

Drs. Richard A. Jahnke and Weiss continue their work on the Bottom Lander, a free-vehicle instrument designed to carry out in situ studies of chemical and biological processes at the sediment-water interface. An engineering and technical group under Dr. Weiss developed the lander to operate for extended periods in water depths down to 6 km, to conduct chemical and isotopic tracer experiments, and to collect seawater and sediment samples. The lander completed three deployments in the equatorial Pacific during leg 3 of Benthic Expedition.

Dr. Harmon Craig and associates in the Isotope Laboratory continue studying mantle volatiles in oceanic and continental hotspots and rift valleys. With Dr. William Rison and Valerie K. Craig, Dr. Craig climbed Karthala Volcano on Great Comoro to sample basalts and active fumaroles on the summit, and then continued similar work on Reunion Island. They explored the southernmost section of the African Rift Valley in Malawi and Tanzania, and ended their work on Santorini Volcano in the Mediterranean. They found that Reunion is a "high helium-3" hotspot, with a helium isotope ratio ($^3He/^4He$) significantly greater than ocean ridge basalts.

Aboard R/V *Melville* during the Benthic Expedition, Drs. Craig and Kyung-Ryul Kim collected the second deep profile of Argon 39 ever taken, north of Hawaii. They proceeded to a study of Loihi Seamount, an active submarine volcano just southeast of Hawaii that marks the current site of the Hawaiian "hotspot." Hydrographic casts over the volcano summit (with shipboard measurements by Dr. Kim) indicated active hydrothermal vents emitting methane and (as found by later laboratory measurements) helium highly enriched in He-3, thus establishing for the first time that methane is a component of submarine volcanic gases.

Dr. Craig, Valerie Craig, and Dr. Kim collaborated with Dr. Jean Francheteau, University of Paris, on a Sea Beam study with R/V *Washington*, on the East Pacific Rise from Easter Island down to 35^0S at the Chile Triple Junction. Their work led to the discovery of a "microplate" (previously postulated from earthquake locations) at the triple junction. This "Juan Fernandez Plate" is bounded on the north by the Bullard Fracture Zone, and on the west by the East Pacific Rise, which is marked by two parallel segments about 30 km apart, extending over a length of some 70 km. Active ridge segments were associated with large hydrothermal plumes (identified by methane) in an integrated study of Sea Beam bathymetry, dredging, and plume measurements in the water column, establishing this as a powerful method for mapping oceanic ridge activity.

From Easter Island, the Craigs and Dr. Kim went directly to Tahiti to catch *Melville* for leg 7 of Benthic Expedition. Here they made another Argon-39 profile south of Tahiti (the third such profile). Then they proceeded toward the Marquesas, sampling the islands of Rurutu (Tubuai Islands), Mehetia (the youngest Society Island volcano), Fatu Hiva, Hiva Oa, and Nuku Hiva for olivine basalts, dredging several seamounts en route. Final work on this leg was done on the islands of Aitutaki and Rarotonga, where they sampled olivine basalts and mantle xenoliths for rare gas studies.

C. C. Chou and Dr. Craig published data on methane in Greenland ice cores showing that the methane mixing ratio decreases exponentially in trapped air in the ice, down to a depth of about 250 m, where it becomes approximately constant at about half the present atmospheric value. This work, which may show the time history of atmospheric CH_4, is being actively continued by drilling a new core in Greenland with on-the-spot sampling by Chou and Dr. John A. Welhan. Dr. Welhan also established the presence of methane in Pacific submarine basalt vesicles by studying gases extracted by crushing fresh glasses.

In Scripps's new Isotope Geology and Geochronology Laboratory, operated by Drs. Macdougall and Günter W. Lugmair, investigations of the mantle sources of flood basalts continued as graduate student John J. Mahoney and two Indian scientists focused on the Deccan and Rajmahal traps of India. In parallel work, Drs. Macdougall and Lugmair continue systematic isotopic studies of East Pacific Rise basalts to compare suboceanic mantle with continental flood basalts. In a related program they attempt to study the temporal evolution of mantle sources of volcanic rocks by investigating ancient terranes. Initial results include the first age determination for the amphibolites of the Banded Gneiss Complex of Rajasthan, India, (3.5 billion years, by the Sm-Nd technique) and an indication that the mantle source was chemically strongly fractionated even at that early time. A geochemical study of western Chinese continental rift volcanics was carried out with Chinese collaborators. Data from this work stressed the importance of a heterogeneous mantle and of mixing processes in the generation of volcanic rocks in this complex tectonic environment. Subcontinental mantle heterogeneity was also studied directly. Dr. Lugmair and a German colleague investigated isotopic disequilibrium in ultramafic inclusions from West German and Mongolian rift volcanics, providing evidence for mantle fractionation processes.

In planetary and solar system studies, Drs. Macdougall and Lugmair's isotopic investigations focused on the earliest solar system evolution. When they analyzed the Sr isotopic composition of carbonaceous chondrites, they found that aqueous activity occurred on the parent body of these meteorites 4.5 billion years ago (when the terrestrial planets were being formed).

The precise measurement of Ni isotopes, from so-called "high-temperature inclusions" from the Allende meteorite, showed that isotopically normal Ni coexists with anomalous Ti. This work, carried out by Dr. Tadashi Shimamura, UC San Diego, and Dr. Lugmair, offers new constraints for models of nucleosynthesis of elements with atomic numbers close to iron, the seed nuclei for heavy elements in stars.

It has been known for 20 years that primitive meteorites

contain a peculiar xenon component (CCFXe) that is enriched up to twofold in the heavy isotopes. Because the isotopic pattern resembles that of xenon from fission of actinides, its source may be an extinct superheavy element. However, experimental techniques available up to now did not permit a direct test of this intriguing hypothesis. Drs. Shimamura and Lugmair, along with two University of Chicago scientists, began studying the isotopic abundances of neighboring elements, especially Ba and the rare earth elements Nd and Sm. If the "superheavy fission" model were correct, then isotopic anomalies caused by fission should be detectable in these elements. No such anomalies were found, and an extinct superheavy element as the source for CCFXe can be ruled out. Direct nucleosynthesis by an r-process (rapid neutron process)-like mechanism within a star close to its supernova stage is the more likely origin of this enigmatic component.

During the same study, one of the isotopes of Nd (^{142}Nd) showed an excess above its normal abundance in nature, which can only be attributed to the decay of an Sm isotope with mass number 146. This Sm isotope has a relatively short half-life of 103 Ma., and would now be extinct if it ever had been produced in significant amounts during a special process of nucleosynthesis. The study shows that indeed it was present 4.56 b.y. ago. The amount calculated is much higher than most currently accepted theories predict and, therefore, puts severe constraints on physical parameters such as time and temperature at which this nucleosynthetic process (p- or γ-process) occurs.

MARINE BIOLOGY RESEARCH DIVISION

Marine Biology Research Division scientists seek answers to fundamental problems in biology and medicine by studying marine organisms and their adaptations to ocean life. Topics under investigation include the social behavior of scalloped hammerhead sharks, bioluminescence, and the effects of oil spills on the marine environment.

Dr. Kenneth L. Smith's group is conducting ecological energetic studies of the deep-sea benthic boundary layer (BBL), which includes the sediments and intermediate overlying water column. The organisms inhabiting this environment can be arbitrarily divided into four consumer groups: sediment community, epibenthic megafauna, benthopelagic animals, and plankton. Estimates of food energy demands, based on in situ metabolism measurements, indicate that the sediment community is the most important consumer group. However, the plankton of the BBL can be equally important. Larger animals that occupy the sediment surface (epibenthic megafauna) and the overlying water (benthopelagic animals) appear to be less important energetically. The input of food energy to fuel these community demands is currently under investigation.

Dr. Robert R. Hessler and Camilla L. Ingram are studying correlations between the vertical distribution of the deep-sea scavenging amphipod *Eurythenes gryllus* with the height of the Ekman layer and vertical eddy diffusion in the benthic boundary layer. This species increases in abundance from the top of the Ekman layer to a peak at 20 m above the sediment. The distribution of this amphipod may result from the vertical diffusion of odors above the sediment, which gives the animal a chemosensory overview of the bottom. Current-meter and trap-catch data are being combined with this information to develop a model to calculate the densities of these highly motile organisms.

Dr. Nicholas D. Holland and a colleague are studying the feeding behavior of feather stars (Echinodermata: Crinoidea) at the Australian Institute of Marine Science. Dr. Holland and another colleague described the fine-structure of the feeding organs of about 20 species of tropical feather stars, giving special attention to possible resource partitioning among sympatric crinoids. Work with other collaborators includes an electron microscopic study of the stalks of sea lillies and larval feather stars, focusing on tissues and cells that may be responsible for stalk motility. A study of the ontogeny of extracellular materials during a sea star's growth and development was completed this year by Dr. Holland and a collaborator from the University of Puerto Rico.

Researchers in Dr. Victor D. Vacquier's laboratory are studying the biochemistry of sperm-egg interaction in sea urchins and abalones. They have identified the proteins of sea urchins' sperm membrane that are involved in triggering the sperm's acrosome reaction. This group is isolating each protein and determining its function in the sperm activation that occurs when the sperm contacts the egg surface. Dr. Vacquier's group is also working on the mechanism of calcium-mediated exocytosis of sea urchin egg cortical granules.

Dr. Frederick I. Tsuji and a University of Oregon student are studying behavior in swarm populations of *Odontosyllis phosphorea*—a worm found along the Pacific coast of North America. These studies are being conducted in Mission Bay, San Diego, where the worms swarm at fortnightly intervals during the first and last quarter phases of the moon from June through October. The swarming starts shortly after sunset, lasts for about 30 minutes, and is accompanied by a bioluminescent display, during which the animals pair and mate.

Animals from deep-sea hydrothermal vents are the focus of Dr. George N. Somero's group. Dr. Horst Felbeck extended his studies of metabolic interactions between vent animals and their bacterial symbionts, while several aspects of sulfide detoxification by the animals were examined by another researcher. Graduate student Susan J. Roberts worked on a wood-eating clam, *Xylophaga washingtoni*, which contains cellulolytic bacterial symbionts. Other studies surveyed the biochemical properties of warm-bodied fishes, and the adaptation of muscle actins to extremes of temperature and pressure.

In Dr. William A. Newman's laboratory graduate students studied the local ahermatypic corals; worked on ascothoracican barnacles; and studied population ecology, assortative mating, and a model for sympatric speciation in obligate commensal coral crabs of the genus *Trapezia*. Dr. Newman continues analyzing the antiquity of abyssal hydrothermal-spring-associated barnacles, with new materials collected by Scripps scientists near 21°N and by French scientists at 13°N. These materials indicate a range extension of 480 nautical miles for the new genus *Neolepas* (previously known only from 21°N); a new species of the relict Jurassic genus *Scillaelepas* at 21°N; and the first Pacific record of this genus other than that from submarine plateaus south of New Zealand. Two new species of *Verruca*, one each for 13°N and 21°N, were found, the first records for this Cretaceous genus from the entire Northeast Pacific. All of these species are interpretable as refugees from shallow-water Mesozoic seas presently surviving under the protection of the hydrothermal environment.

Dr. A. Peter Klimley conducted field studies in the Gulf of California on the behavior of the scalloped hammerhead, *Sphyrna lewini*. Complex social behavior, including communication within schools at an offshore seamount, was observed using video techniques. Ultrasonic telemetry tracking revealed the shark's remarkable ability to return to the seamount after extensive night excursions into the surrounding pelagic environment. Dr. Klimley also used capture records of the white shark, *Carcharodon carcharias*, to describe its life history along the western coast of North America, and to argue that the distribution of this species is linked to the availability of pinniped prey to large adult sharks.

L. D. FORD

Dr. Joan G. Stewart examines algal turf from a local intertidal rocky beach. Inset: The Corallina *(3.3x magnified view) is a dominant plant in this vegetation.*

Dr. Claude E. ZoBell continues to direct research into the effects of oil spills on the marine environment, with special reference to oil dispersants and the biochemical activities of bacteria. He is also investigating the microbial aspects of primary film formation on Ocean Temperature Energy Conversion seawater conduits.

A long-term study of the interactions between co-occurring plants on many flat, intertidal, rocky beaches in southern California entered a second phase. Dr. Joan G. Stewart noted that in many of these habitats the vegetation is dominated by a low mat of agal turf, which is bordered on the seaward side by beds of the sea grass *Phyllospadix*. The study emphasizes the successional processes that regulate the establishment of the two assemblages. Descriptive data document seasonal fluctuations in the species' relative abundance in four sites between Point Loma and La Jolla.

Work in Dr. Andrew A. Benson's laboratory reveals much of the mechanism by which aquatic algae and plants metabolize and detoxify the arsenic that competes with the essential plant nutrient phosphate. Dr. Francis C. Knowles elucidated the nature of the biological reductases that render arsenic toxic to most organisms, including man. Such studies will establish guidelines for evaluating arsenic pollution associated with exploitation of geothermal energy in California.

Carotenoids, the blue light absorbing pigments of marine plants, continue to be a focus of Dr. Francis T. Haxo's research. Collaborative studies on carotenoid pigment patterns in free-living and symbiotic dinoflagellates indicate that unique carotenoid disaccharides occur widely among the Dinophyceae and may be considered as a new chemosystematic marker for this algal group. A preliminary examination was made of the spectral absorbance properties and pigments of *Noctiluca miliaris*, one of the heterotrophic dinoflagellates reported to cause striking discolorations of marine waters. *Noctiluca* cells fractionated from local mixed phytoplankton blooms and held in the laboratory without algal food retain a pink-orange color and display a characteristic, 2-3-peaked, blue absorbance spectrum. Two as yet unidentified xanthophylls appear to be major determinants of coloration within the *Noctiluca* cell.

In the laboratory of Dr. Ralph A. Lewin, the physiological and biochemical processes associated with the shedding of flagella by algal flagellates are under study. These organisms, common in phytoplankton, tend to shed their flagella when subjected to unfavorable conditions. Researchers found that the shedding process, termed autotomy, always occurs at a specific site (just inside the cell membrane at the base of the flagellum). Shedding seems to be associated with a cap-and-ring structure, the so-called transition apparatus, visible only in electron micrographs of thin sections. At room temperature, the whole process of abscission and healing of the flagellar stump may take less than one second. In marine species, the removal of divalent cations, especially Mg^{++}, from seawater triggers flagellar shedding. Cells retain their flagella when either Mg^{++} or, to a lesser degree, Ca^{++} is replaced in the medium. Thus, the sensitivity of flagellates to certain ions is unexpectedly similar to that of nerve cells, and shows other parallels with such membrane depolarization phenomena as nerve conduction. In freshwater flagellates, shedding seems to require divalent cations, notably Ca^{++}; and is inhibited by monovalent cations, notably Na^{+}.

Dr. Kenneth H. Nealson's group is investigating several aspects of marine microbiology: bioluminescence (using an offshore monitoring station); mechanisms of bacterial light emission; mechanisms of manganese oxidation and reduction by microbes; and the activities of metal-precipitating bacteria in nature. Of particular note is graduate students' work on the explanation of several new physiological controls on the bioluminescence system, the cloning of the genes from *Vibrio fischeri* into *E. coli*, the isolation and study of several pure cultures of manganese-reducing bacteria, and modeling to explain bacteria's role in manganese reduction in nature.

Dr. Benjamin E. Volcani's group studied silicon's function in metabolism and cell-wall morphogenesis in diatoms. Dr. Pinakilal Bhattacharyya began characterizing the two purified silicate ionophores from *Nitzschia alba*. The ionophores inhibit diatom growth, and the inhibition is counteracted by silicate. 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. Graduate student Chia-Wei Li determined that microtubules, serving as cytoskeletons, are associated with the diatom wall components that are initiated from cytoplasmic protrusions. Graduate student Jerry D. Jacobs isolated high-molecular DNA from *C. fusiformis* and separated it into distinct groups on the basis of AT content. Two distinct, small closed circular DNA molecules were purified from one of these groups. A UC San Diego graduate student analyzed the accumulation patterns for the mRNA and polypeptide populations of *C. fusiformis*, and found that specific pattern changes are related to the illumination condition, the presence or absence of silicon, or to the cell cycle "program."

Dr. Ted E. DeLaca is studying the distribution, ecology, and physiology of benthic foraminifera. He is concentrating on the trophic positions (sources of nutrition and losses to predation) and the metabolic rates of several large Antarctic species of foraminifera. His investigation of the effects of metazoan disturbance and predation on foraminiferal populations depends heavily on environmental analyses. Dr. DeLaca is also evaluating the significance of benthic foraminifera in temperate, tropical, and deep-sea environments.

MARINE LIFE RESEARCH GROUP

The Marine Life Research Group (MLRG) is the University of California's representative in the California Cooperative Oceanic Fisheries Investigations (CalCOFI) program. Since 1947, CalCOFI scientists have investigated the nature, environment, ecology, and general biology of the pelagic fishes and associated organisms of the eastern North Pacific Ocean. Testable hypotheses have been formulated about physical, biological, and chemical events in the eastern North Pacific and the world ocean. In 36 years of activity, CalCOFI scientists have collected an extensive time series of hydrographic and biological data, against which anomalous conditions may be contrasted. During 1982-1983, the large-scale thermal structure of the California Current showed several anomalous conditions normally associated with what is called a Californian El Niño.

The mean sea level along the coast of California varies seasonally and yearly, and shows a long-term rise. The mean sea level at the Scripps Pier has risen about 10 cm since 1925. The El Niño event of 1982-1983 is characterized by warmer waters and a stronger northward flow during the winter along the coast of California. The northward flow is associated with an upward slope of the sea surface toward the coast. The monthly sea level off La Jolla rose strongly in the summer of 1982, and in November 1982 reached the greatest elevation ever measured there—21 cm above the long-term November mean. The surface began to drop in late winter and by March was only about 10 cm above the mean.

High sea-surface temperatures (SST), depression of the thermocline by 50 m or more, and the presence of anomalously warm subsurface waters were the subjects of Dr. James J. Simpson's research. The subsurface anomaly was much greater than the SST anomaly. These persistent (>6 months) structures, coupled with unusually high sea levels along the North American coast, confirmed that a major

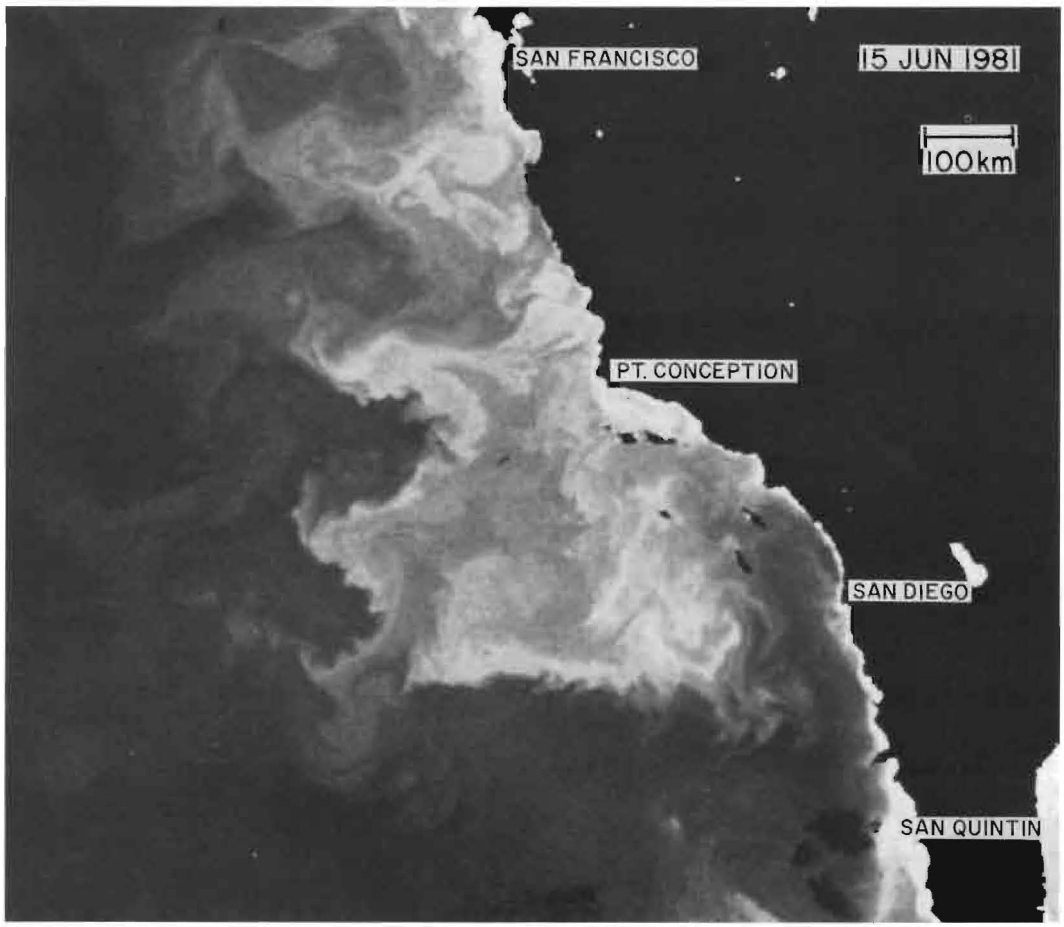
Californian El Niño occurred during 1982-1983. The data support the conclusion that the expansion and intensification of the Aleutian low and the decrease in strength of the Pacific high produced an anomalous basin-wide atmospheric circulation, which coupled directly with the large-scale oceanic wind-driven circulation to produce the Californian El Niño. The enhanced transport from the west and south, which such a circulation would produce, was consistent with the observed temperature and salinity characteristics. The Californian El Niño was probably related to the more frequent equatorial El Niño through an atmospheric teleconnection between equatorial SST and the atmospheric Hadley circulations.

Dr. John A. McGowan and two colleagues analyzed the 30-year time series of physical and biological data from the California Current. He is collaborating with Drs. Simpson and P. Peter Niiler in a study of the Californian El Niño. Large-scale, interannual cycles of secondary productivity were discovered, and are well correlated with changes in the strength of the current. An increase in the southward transport of cool, low-salinity water from the north led to large-scale increases in the abundance of plankton, while weakening of the flow led to decreases in plankton. The scientists hypothesized that this relationship resulted from changes in input of high-nutrient water caused by the strengthening and weakening of the current. Many periods of low transport were associated with El Niño events in the eastern tropical Pacific. During the present El Niño event, the chlorophyll maximum layer seaward of 200 km deepened in comparison to the long-term mean. This could have a significant impact on zooplankton abundance and distributions, and upon predators higher in the food chain. Graduate student José Peláez-Hudlet obtained the unexpected results shown in the accompanying illustration during a study of large-scale patterns of chlorophyll abundance.

Dr. Niiler deployed current meters on ten moorings to measure the currents from 300-m depth to bottom in the Kuroshio Extension at 152°E. He compared the Kuroshio mesocale pattern and circulation with the Gulf Stream in the North Atlantic, and found that deep currents under the Kuroshio are much weaker. In the Storm Response Experiment the storm response of the mixed layer was measured by an array of 6 buoys. Unexpectedly, mixed-layer deepening was found to be very different over a 250-km separation in the array.

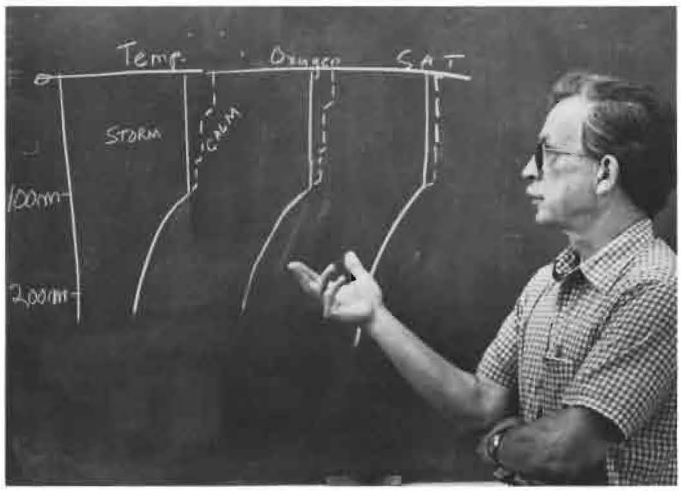
Dr. Edward Brinton is examining population dynamics of euphausiid crustaceans in the California Current using extensive measurements of dissolved nutrients, plant pigments, and primary production made during the ten CalCOFI cruises of 1969. He is examining larval recruitment and growth in offshore and nearshore euphausiid species in relation to the seasonal pulses of coastal nutrient renewal and their influence upon inhabitants of the body of the current system. From April to September 1969, coastal upwelling was more pronounced than usual, developing northward from Punta Eugenia in Baja California to the coast of central California. This upwelling was associated with an above-average zooplankton biomass in almost all regional populations.

The pattern of saturation of dissolved oxygen has been used by Joseph L. Reid to estimate the maximum depth of winter convection in the North Pacific Ocean. He noted that in winter the ocean's upper layer in high latitudes is substantially undersaturated with oxygen. This occurs either because the waters are cooling faster than they can equilibrate with the atmosphere or because the vertical stirring in winter mixes the upper layer with the deeper, undersaturated water. North Pacific storms may produce an upper layer as thick as 250 m,



J. PELÁEZ-HUDLET

Processed chlorophyll-like pigment image off the Californias from the Nimbus-7 Coastal Zone Color Scanner. Data collection time was about four minutes. Lighter tones correspond to higher chlorophyll concentrations (land and clouds are masked in black). A latitudinally oriented sharp boundary south of San Diego was unexpected, as was the meandering, meridionally oriented front 200 to 500 km off the coast; this front was associated with four large, low-chlorophyll eddies.



L. D. FORD

Joseph L. Reid explains how the degree of oxygen saturation may remain uniform vertically after a storm even though temperature structure may have changed.

vertically but not horizontally homogeneous. However, immediately afterward, lateral spreading may restratify the upper 100 to 150 m of the column. The degree of oxygen saturation, however, may be made nearly uniform horizontally over several hundred kilometers by a storm, and the lateral mixing that afterward restratifies the temperature and salinity structure may leave a nearly uniformly saturated upper layer, whose thickness will still reflect the maximum depth of previous convection.

Greenland Sea measurements taken from February through April 1982 show quite low (92% to 95%) saturation values in the upper layer, but they are nearly uniform down to a maximum depth of 700-800 m. This indicates that winter convection did not penetrate to great depths, with renewal of the abyssal waters, but was confined to the upper part of the ocean, extending less than 1 km below the surface.

Dr. James H. Swift has been examining the origin and circulation of the waters of the Norwegian-Greenland Sea and the deep Arctic and North Atlantic oceans, using a combination of historical and recent hydrographic data. He concluded that the deep Arctic Ocean is not merely a sink for dense waters originating elsewhere but is also a source of deep water for the adjoining Norwegian-Greenland Sea. Dr. Swift also investigated recent large-scale temperature-salinity shifts in the deep water of the northern North Atlantic, which may be tied to weather pattern changes since the 1950s and 1960s.

The mechanisms maintaining the vertical distributions consistently observed in the upper 175 m of the North Pacific Gyre are being studied by Dr. Elizabeth L. Venrick. Preliminary analysis of phytoplankton samples indicated winter persistence of the vertical distribution pattern characteristic of summer months, although the transition between shallow and deep flora is depressed 30 to 50 m. Large-scale patterns (to 1000's of kilometers) were sampled in 1982 on a transect from Honolulu to San Diego.

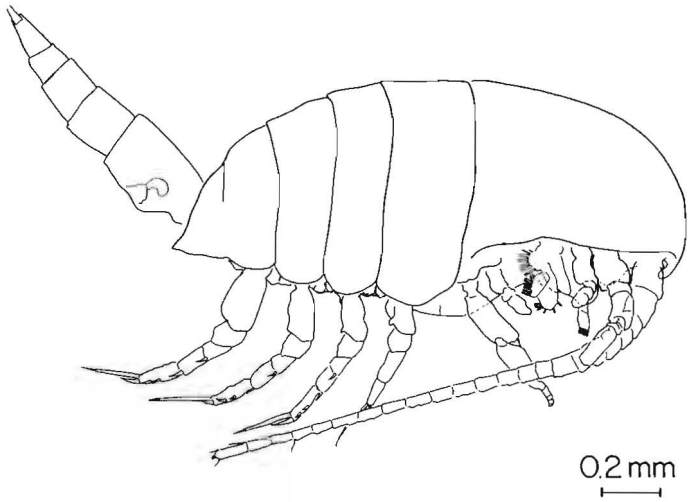
Dr. Abraham Fleminger added the first calanoid copepod to the unique bathyal, suspension-feeding, benthic assemblages living immediately adjacent to hydrothermal vents at ocean-floor spreading centers on the East Pacific Rise. The unusual copepod *Isaacsicalanus paucisetus* is a new genus and species (named in honor of the late John D. Isaacs). *Isaacsicalanus paucisetus* occurs in swarms within 1 m of the sea floor. Phylogenetic analysis supports the hypothesis that *Isaacsicalanus* occupies a highly derived position within the family Spinocalanidae.

In terms of biomass, the dominant California Current planktonic copepod is probably *Calanus pacificus californicus*. Huge concentrations occur seasonally (spring) in cool-water plumes off headlands between Cape Mendocino, California, and Magdalena Bay, Baja California. Populations in the mixed layer decline precipitously in late summer and fall, but scattered evidence indicates that relatively large quantities of late juveniles occur in an inactive resting condition in slope water at the depth of the undercurrent. These may constitute the stocks that seed newly upwelled coastal waters in the subsequent spring and give rise to the next reproductively active population.

The utilization and turnover times of amino acids by heterotrophic bacteria were determined in sea-surface films and in the water column by Dr. Angelo F. Carlucci. Uptake and respiration of amino acids (e.g., ^{3}H-glutamic) were measured under controlled conditions. His associates determined the ambient concentrations of amino acids with high-pressure liquid chromatography. Turnover times for glutamic acid in surface films of the Southern California Bight ranged from a few hours (nearshore) to days (offshore). The most rapid turnover times within the water column were noted in the upper 50 m of water. It appears that heterotrophic bacteria are important agents in the rapid recycling of amino acids, especially in surface films and in the euphotic zone of the sea.

Graduate student Alan L. Shanks is determining how planktonic larval stages of coastal benthic organisms return to shore. A fortnightly cycle in the recruitment of crab megalopae suggests that they may be carried ashore at the surface on tidally forced internal waves. Banded slicks associated with these internal waves sometimes transport drogues several kilometers shoreward. On these occasions, megalopae and other larval forms are 10 to 100 times more concentrated in slicks than in water between slicks. These data suggest that transport in slicks associated with tidal internal waves may be a means for the onshore migration of megalopae and many other larval forms.

Dr. Lanna Cheng has discovered that the sea-skater, *Halobates*, which is the only insect genus to be found in the open ocean, is one of the important food items for at least 4 of 18 seabird species studied: the blue-gray noddy, Bonin petrel, gray-backed tern, and Bulwer's petrel. Blue-gray noddies may at times feed exclusively on the sea-skaters and thus appreciably reduce the population of these insects within the foraging territories of the birds.



Drawing of a newly named calanoid copepod Isaacsicalanus paucisetus. *This copepod lives immediately adjacent to the hydrothermal vents on the East Pacific Rise.*

MARINE PHYSICAL LABORATORY

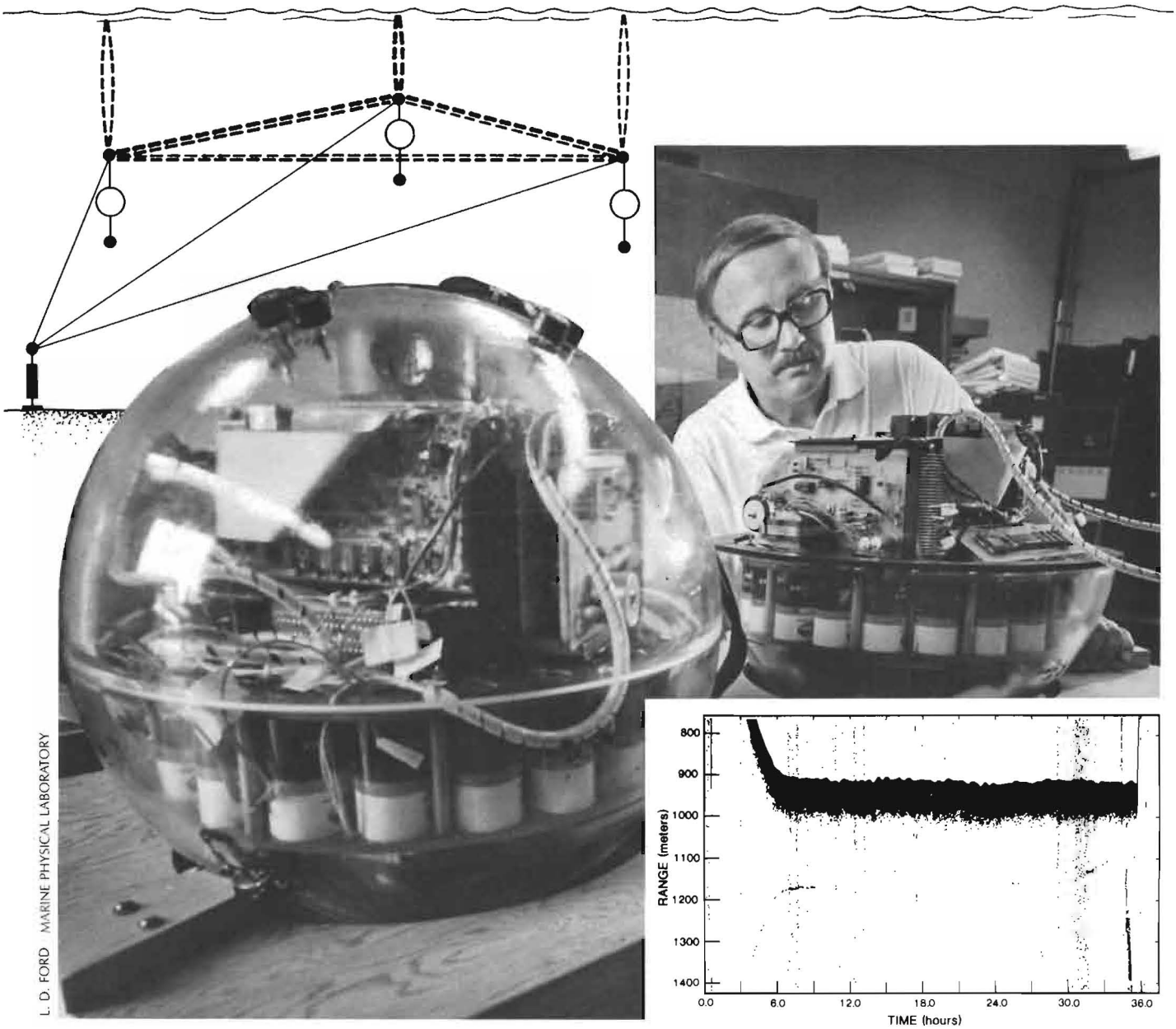
The central research themes at the Marine Physical Laboratory (MPL) are marine physics/geophysics, ocean environmental acoustics, signal processing, and ocean technology. MPL director Dr. Kenneth M. Watson guided seagoing investigations in east, central, and equatorial Pacific waters.

Dr. Watson continues to study mesoscale flow, which is especially effective in transporting internal wave energy near the inertial frequency to high vertical wavenumbers. Horizontal variability in the mesoscale structure provides a mechanism for transferring energy from the mesoscale flow to internal waves.

Dr. William S. Hodgkiss and colleagues applied spatial filtering and high-resolution spectral analysis techniques to problems in underwater acoustics. The capability of adaptive array processors to cancel the surface reverberation from an active sonar is being explored. The properties of several adaptive high-resolution spectral analysis techniques are under investigation, with a focus on the Doppler sonar problem.

The Swallow Float Program is being carried out by Dr. Hodgkiss and Dr. Victor C. Anderson to develop an independent sensor array for measuring infrasonic background noise in the ocean in the 1-to-10-Hz region. An autonomous buoy capable of recording the components of particle velocity in the 1-to-10-Hz band and also able to generate and receive high-frequency acoustic positioning signals was developed for this project. The Swallow float is neutrally buoyant and can be ballasted for any desired depth; drifting freely, it is not subject to any flow disturbance.

The Swallow float contains three geophones to measure the components of particle velocity in the 1-to-10-Hz band, a compass for buoy heading, an acoustic transponder for localization, a solid-state memory data buffer, a digital tape data recorder, and an acoustically actuated ballast release. Limited by tape recorder capacity, the maximum submergence period of the float is about 60 hours. A prototype buoy has



L. D. FORD MARINE PHYSICAL LABORATORY

Top left: Diagram of a three-element Swallow float array. Center: Engineer Gregory L. Edmonds prepares a Swallow float for deployment (in left foreground is an assembled float). Lower right: An example of the raw sonar surface echo record from a Swallow float taken in July 1982.

been designed, built, and successfully deployed at sea. Several more elements are under construction.

Dr. Henry D. I. Abarbanel studied the development of a strange attractor in the oceanic internal wave field. In a model that drove the ocean with a "Bunsen burner" at the surface, he found a strange attractor in a few-mode realization of the internal wave field. In phase portraits of two of the velocity field modes, he observed that the motion was chaotic and appeared to lie on a strange attractor. Dr. Abarbanel and two graduate students continued investigating the effect of collisions or friction on the evolution of linearly unstable plasmas. They found that the spectrum of the linear operator governing the instability is significantly altered when a small amount of Fokker-Planck type collisionality causes relaxation in the system. Dr. Abarbanel is also developing a model of the mesoscale oceanic flows driven by surface wind stresses, which in turn drive the internal wave field by vertical and horizontal stresses.

Dr. William R. Young is conducting theoretical analyses of general circulation and the mixing of passive scalars. Previous theories of wind-driven circulation have been generalized. Dr. Young has developed a three-dimensional theory of circulation in the Sverdrup interior of a wind gyre. He is also studying the effect of western boundaries in mixing passive scalars.

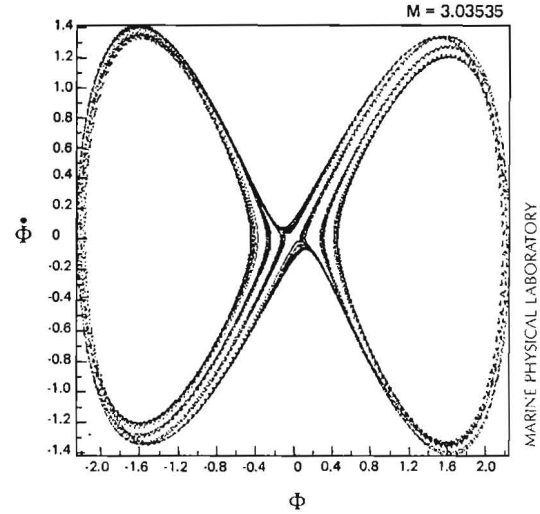
Dr. Frederick H. Fisher's research group is involved in the development of a new 64-element digital vertical acoustic array, and long-wavelength sea temperature profiling. They are also investigating shallow-water noise and propagation. Dr. Cheng C. Hsu confirmed the existence of calcium sulfate relaxation in a 0.011 molar solution. He also measured the pressure effect on the calcium sulfate solution, and conducted similar studies on sound absorption in seawater. Additional studies of ion pairing and sound absorption in hydrogen chloride-magnesium sulfate and hydrogen sulfate-magnesium sulfate solutions were made by Dr. Fisher. In collaboration with Dr. Fisher, a visiting scientist conducted studies of ion speciation and acid-base chemistry in seawater.

Dr. Robert Pinkel's research group studied the physics of internal wave motions in the top kilometer of the sea. The researchers used high-power Doppler sonars mounted on the research platform FLIP to profile the oceanic velocity field. The sonars transmit sound energy in a narrow beam, which scatters off plankton. From the Doppler shift of the returning echoes, scientists can determine the velocity of the scatterers, and hence the water mass.

Preparations are under way for a major multi-institutional data collection cruise. FLIP is being equipped with a set of six Doppler sonars (four downward slanting and two horizontal), a profiling CTD, and a host of other sensors. This is a technically sensitive endeavor, because unwanted acoustic scattering from the sea surface can dominate the much weaker signal from the drifting plankton.

The Deep Tow group conducted two major expeditions. One was an NSF-funded investigation of a propagating rift site in the Cocos-Nazca spreading system at 2° 30'N, 95° 30'W. This was the first major expedition to use the new Sea Beam multibeam echo-sounder system on R/V *Thomas Washington* together with the Deep Tow. Drs. Richard N. Hey and Robert C. Tyce led an expedition in which Sea Beam was used to establish larger-scale topographic patterns. These patterns generally confirmed the expectations derived from Dr. Hey's models. Deep Tow transponder navigated surveys were then carried out to produce side-looking sonar imagery, photographs, and a detailed areal magnetic survey near the growing and dying ridge tips.

The other major expedition aboard R/V *Melville*, under the direction of Drs. Fred N. Spiess and Robert R. Hessler, focused on two aspects of manganese nodule resources. The first was an investigation of acoustic backscatter from manganese-



The phase plane motion of two modes of the internal wave field when the energy stress on the system (parameterized by the number M) has reached a value that drives the asymptotic state onto a strange attractor. The signal for this is the never crossing curve in the phase plane, which does not fill a two-dimensional area, but a "piece" of the plane with dimension between one and two.

nodule-covered areas, using sounds at seven frequencies from 4.5 to 160 kHz. This was integrated with another study of the environmental effects of a trial mining effort. The primary tools used were the Deep Tow system—particularly side-looking sonar and photo/TV capabilities, and a special acoustic backscatter package—and box coring to obtain sediment and manganese nodule samples. Both the Deep Tow and the box corer were positioned using sea-floor acoustic transponder navigation. The expedition successfully located, mapped, and photographed the mining tracks; made acoustic measurements over a wide range of nodule distributions; and collected 16 consecutive box core samples.

Development of a remotely controlled undersea vehicle (RUM III) continues under the direction of Dr. Anderson. RUM III will operate as a towed vehicle or as an ocean bottom crawler to 6000 m below the surface. Subsystems include seawater hydraulics; a 4.2-m manipulator boom; a titanium truss frame; a rotating turret for positioning the manipulator, TV camera, lights, thrusters, and side-looking sonar; a passive cable accumulator to compensate for ship heave; rotating counterweights for balance control; thrusters for orientation and movement above the ocean floor; and tracks for movement on the ocean floor. The vehicle will be controlled by several microcomputers located on RUM III and the support ship.

NEUROBIOLOGY UNIT

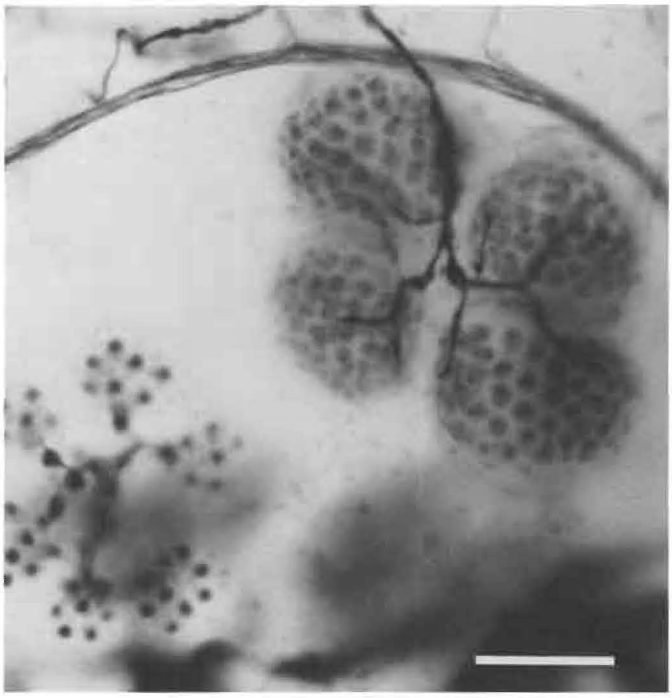
The Neurobiology Unit is associated with Marine Biology and the Marine Biomedical Program. The unit's emphasis is on behavioral, anatomical, and physiological studies.

Dr. Theodore H. Bullock is concerned with comparative neurology and identifying functional and structural brain differences to account for the great behavioral differences that are prime achievements of evolution and determinants of ecological success. One project is a comparison of brain waves or ongoing electrical activity and the evoked potentials or responses of nerve cell arrays to stimuli in annelids, arthropods, molluscs, and vertebrates. With Dr. G. David Lange and Michael C. McClune, Dr. Bullock is developing a new measure of synchrony of neuron populations and fine-structure of the brain waves in space; the coherence/distance plot or rate of decline of congruence of activity at each frequency with

separation of recording loci. This requires implanting a number of electrodes into the brain, recording its activity under various conditions, and conducting a large-scale computer analysis. Octopuses (up to 22 kg) and thornback rays are special objects of attention. Dr. Bullock and colleagues are analyzing bandpass filtered and rectified brain waves to examine waxing and waning energy in each band, especially to predict varying responses to stimuli. Octopus activity, in contrast to that of other invertebrates, is surprisingly similar to vertebrate activity.

The elaborate system of sense organs and brain centers in certain fish for sensing feeble electric fields is being studied. Physiological recordings from thornback rays have revealed two distinct forebrain electroreception centers, with different dynamic response characteristics—perhaps parallel processing for different functions. An iontophoretic local injection of cobaltous-lysine into nuclei was used to visualize new electrosensory pathways in the brain stem. Supersensitive electroreceptors in these rays (ampullae of Lorenzini) are all depressed during expiration and excited during inspiration; this must interfere with the detection of extrinsic sources of electric signals, such as prey, and the brain might find means of canceling the respiratory modulation. It was found that it does already in the first center in the medulla, by a process called in-phase rejection.

Dr. Harold H. Zakon discovered that juvenile electric fish *(Sternopygus)* have only one electroreceptor organ per nerve fiber in the skin; these increase, by a fissionlike process, to 10-20 organs per fiber as the fish grow. These organs are sharply tuned to the individual fish's own electric organ discharge frequency. Dr. Zakon finds that one basis for this is a damped ringing of the receptors, which appears to be an active cell oscillation. It can be studied in isolated preparations of skin to reveal its ionic dependence; calcium and potassium but not sodium current channels in some way vary between differently tuned individuals, and change with hormones.



H. H. ZAKON

Silver-stained, whole mount of a young Sternopygus's *cheek skin showing clusters of sensory cells (larger gray or smaller dark blobs). Each cluster forms a sense organ; the four in the upper right, innervated by one nerve fiber, form a "tuberous electroreceptor" tuned to the fish's relatively high-frequency electric organ discharge. The six in the middle left form an "ampullary receptor" for low frequencies. Bar = 50μm.*

CALIFORNIA SPACE INSTITUTE

The California Space Institute (Cal Space), under the direction of Dr. James R. Arnold, is a multicampus unit of the University of California. Cal Space, headquartered on the Scripps campus, supports and engages in space-related studies.

The major themes of Cal Space are remote sensing and climate research. Assistant director Dr. Catherine H. Gautier is leading several projects focusing on large-scale air-sea interactions. A major five-year program, Tropic Heat, will explore these interactions in a large area of the equatorial Pacific. Dr. Gautier's group will be responsible for much of the satellite remote sensing portion of the study. Dr. Gautier chaired a workshop at Scripps on "Exploring Recent Warming in Pacific Waters" (El Niño). Cal Space has a statewide competitive minigrant (seed project) funding program for space-related research.

The National Aeronautics and Space Administration's (NASA) use of the shuttle for space transportation is now established. New plans are under discussion, and Cal Space researchers are studying incremental, modular approaches that can lower costs and increase capabilities for operations in low earth orbit. Attractive possibilities involve the use of shuttle external tanks, and the gravity-gradient tether concepts developed earlier. With NASA support, Cal Space scientists are also studying processes for using lunar soil as raw material for producing propellants and structures for use in space. Finally, Cal Space and the Solar System Exploration Committee are developing plans to use existing commercial spacecraft for mapping and exploratory missions to the moon and asteroids.

INSTITUTE OF GEOPHYSICS AND PLANETARY PHYSICS

The San Diego branch of the Institute of Geophysics and Planetary Physics (IGPP) is located at Scripps Institution and is linked to Scripps by a variety of scientific associations. Other branches of IGPP are located on the Los Angeles and Riverside campuses.

Dr. Duncan C. Agnew is studying ocean tide loading, comparing the displacement loads predicted by different ocean models. He also is working on sea-level variations in the Aleutian Islands, finding the response to weather to be like that at deep ocean islands. He finds that past estimates of tidal energy flux into the Bering Sea were probably too large. Dr. Agnew is also studying methods of analyzing geodetic data in the presence of long-term correlations.

Operation of the Cecil and Ida Green Piñon Flat Observatory continues under the direction of graduate student Frank K. Wyatt, assisted by Drs. Agnew and Jonathan Berger. Twenty-six projects from 18 institutions have been set up at the observatory. Recent progress in the measurement of crustal deformation has included installation of "optical anchors" at each end of the 535-m-long tiltmeter, and a cooperative study with the Carnegie Institution of Washington on the behavior of three Sacks-Evertson borehole strainmeters installed at the observatory.

A study of the electrical conductivity of the lower mantle was continued by Dr. George E. Backus. This work is based on the magnetic jerk of 1969 and shows that the data do not yet require a poor conductor in the lower mantle. Dr. Backus also extended the recent work of two scientists on estimating crustal noise in satellite measurements of Gauss coefficients.

Dr. Robert L. Parker and a colleague applied a novel method (developed earlier in collaboration with Dr. Backus) of representing the earth's main magnetic field to a very

large volume of observations made by a satellite-borne magnetometer. The new field model suggests that previous analyses have attributed unwarranted magnetic energy to the core in spherical harmonic degrees above ten. This may have important consequences both in the interpretation of crustal magnetic anomalies and in the description of the field at the surface of the core. Also, Dr. Parker is studying a nonlinear inverse problem arising in electrical prospecting. In this problem there is a surprising kind of linear superposition, the "bilayer expansion." Certain elementary solutions can be combined linearly to represent an exact solution to the nonlinear equation. The bilayer expansion promises to be widely applicable to a variety of other systems.

Cooperative seismic studies with Mexico, including investigations of seismic hazard, earthquake strong motion, earthquake mechanism, and earth structure, are being continued by Drs. James N. Brune, John G. Anderson, and Michael S. Reichle. They use theoretical, numerical, and physical models to understand and estimate the probabilities of large ground accelerations that might damage sensitive structures such as nuclear power plants.

Dr. Anderson and a colleague worked out the constraints that the average slip rate on a fault places on earthquake occurrence relations. Dr. Anderson is comparing these predictions to data gathered throughout California. He also continues theoretical studies of strong ground motion caused by kinematic models of faulting during an earthquake.

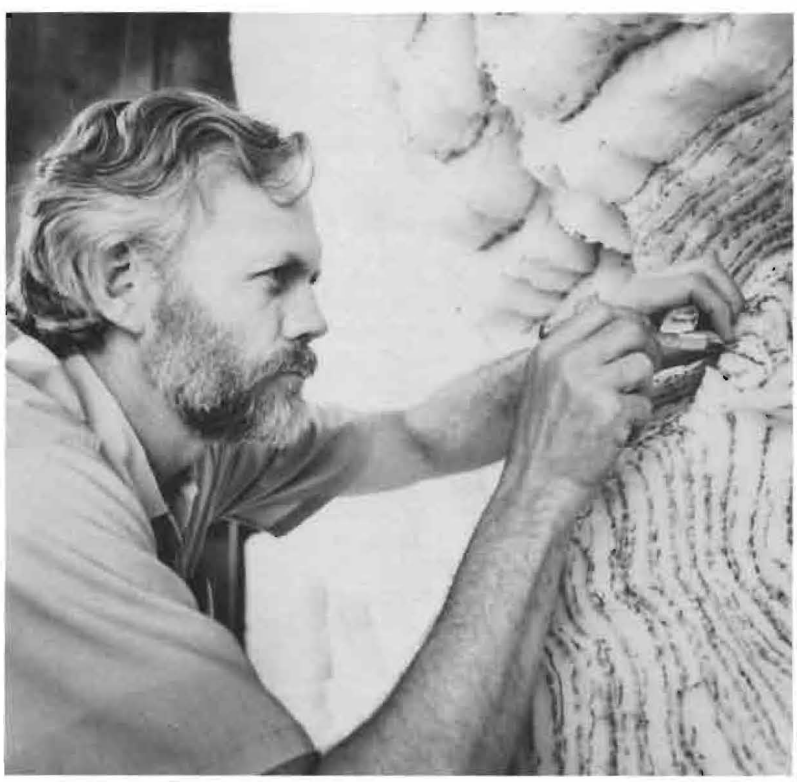
Three long-period seismograph stations are being operated in Mexico by Dr. Brune, graduate student Joan S. Gomberg, and a University of Nevada colleague as part of a cooperative U.S.-Mexico project to study the earth's crust and mantle structure in the central highlands of Mexico and the mantle structure along the cordillera of western North America.

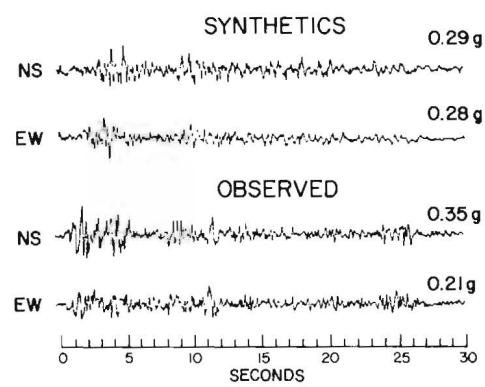
Dr. Reichle is working on a cooperative program to assess seismic hazards in the California-Baja California border region. The program includes geologic mapping of the Tijuana River Valley, seismicity studies of the San Miguel fault zone, and analysis of local triangulation data for strain accumulation near San Diego faults.

Dr. Alan D. Chave continued work on electromagnetic induction associated with ocean currents. In conjunction with Dr. Jean H. Filloux, he separated the electromagnetic fields at a sea-floor site into those parts produced by the ionosphere and ocean, and found them to be similar in magnitude. Model studies indicate that a combination of barotropic long waves and internal waves explains the results. Graduate student Jeffrey J. Park and Dr. Chave developed a new method to calculate magnetotelluric response functions that avoid the usual assumptions about noise distribution.

Dr. LeRoy M. Dorman continued work on the fundamental problem of seismic exploration, the inference of the earth's velocity structure from observations on its surface. The principal method of interpreting refraction data requires measuring the apparent velocity of seismic waves past the recording site. This velocity is then used as the independent variable in representing travel time T and distance X. T and X are linearly related to the model variables describing the earth. A derived variable $\tau = T - \rho X$ has long been used because it minimizes the effect of errors in measuring the velocity. Using τ and X jointly to represent the data minimizes the adverse effects of inhomogeneities in the earth as well as the effects of the errors in estimating velocity.

Dr. Dorman and graduate student Allan W. Sauter are studying the effects of the physical characteristics of ocean-bottom seismographs on the signals they record. These effects include the response of the instrument itself and the effects of the instrument's presence. The latter mechanism appears to be significant because the instrument acts as a mass anomaly that





Left: Dr. James N. Brune models the topography of a region that recorded ground accelerations over 1 g in the 1971 San Fernando earthquake. Upper right: Synthetic (theoretical) seismograms for the 1940 El Centro earthquake (upper traces) calculated by Dr. Luis Munguia, CICESE, Mexico, compared with observed seismogram (lower traces). Bottom right: Furrows in a farmer's field offset by the 1979 Imperial Valley earthquake. Fault strikes across field from left to right, and offsets the furrows on the far side about ½ meter to the right.

must be moved by the soft sea floor as the sea bed moves with the passage of seismic waves.

Drs. T. Guy Masters and Gilbert, and Park investigated strong mode coupling in the earth's seismic spectrum below 3.0 mHz. There are many observations of spectral peaks at toroidal periods on vertical accelerometers. This indicates toroidal-spheroidal mode coupling, and preliminary calculations show that nearly resonant coupling by the Coriolis force explains most of the observed effect. Nearby modes that are coupled are pushed apart in frequency and pulled together in attenuation, in agreement with observations. The necessity of including attenuations in the theory has led to the development of a Galerkin procedure for the eigenvalue problem which, because of the Coriolis force, is quadratic rather than linear.

Dr. John W. Miles continued his work on nonlinear waves and diffraction theory. This year he published three papers on the diffraction of surface waves by a periodic row of submerged ducts, a configuration of practical importance for wave-power absorption. Dr. Miles is now working on chaotic motion in dynamical systems that are governed by sets of nonlinear differential equations.

Work in ocean acoustic tomography was continued by Drs. Walter H. Munk, Peter F. Worcester, Robert A. Knox, and Bruce D. Cornuelle. Their principal effort this year was a preliminary analysis of the 300x300-km experiment southwest of Bermuda, which took place in 1981.

An experiment to test reciprocal transmissions on the 300-km scale for measuring currents was completed. However, equipment failures make it necessary to repeat the test. In addition to these experiments and their analysis, some theoretical studies dealing with inversion techniques and normal mode analysis were performed jointly by Dr. Carl I. Wunsch, Massachusetts Institute of Technology, and Dr. Munk.

Drs. John A. Orcutt and Allen H. Olson completed work on several new inverse methods for dealing with seismic reflection and refraction travel time data and used these methods to analyze data collected in the Imperial Valley by the U.S. Geological Survey. They found that the metamorphosed sediments at the base of the valley achieve very high velocities (6.2-6.5 km/s), and little contrast of physical properties occurs at the interface between the sediments and the crystalline basement. Drs. Orcutt, Thomas H. Jordan, and Brune have established a new laboratory at IGPP for the growing global digital seismic network and, with Drs. Gilbert and Masters, have begun to exploit a new computer network that closely links the laboratory with another facility on campus.

Dr. Richard L. Salmon continued work on a theoretical model of large-scale ocean circulation based upon the motion of Lagrangian fluid particles.

Dr. Robert H. Stewart works jointly with the California Institute of Technology's Jet Propulsion Laboratory and IGPP, where he is writing a book: "Methods of Satellite Oceanography."

Bernard D. Zetler continues ocean tide research, in particular on long-range forecasts of extreme tides on the California coast, and on improving tide predictions by using node constituents in place of annual approximations to the 18.61-year cycle in the longitude of the moon's node.

Project IDA (International Deployment of Accelerometers) is run by Drs. Agnew, Berger, and Gilbert. Eighteen long-period seismic stations are now operated. The newest stations are at San Juan, Puerto Rico; Alert, Canada; and Beijing, People's Republic of China.

INSTITUTE OF MARINE RESOURCES

The Institute of Marine Resources (IMR), directed by Dr. Fred N. Spiess and headquartered at Scripps, fosters research and communications throughout the University of California system. To encourage intercampus activities, IMR publishes a catalog of marine-related courses offered through the UC campuses and a directory of marine research assets (facilities, collections, etc.) that includes the California State University system. So far five UC graduate students have been supported by the IMR Student Interchange Program, which allows them to take advantage of marine-oriented course work or research facilities on UC campuses other than their own.

During the past year IMR helped present two major conferences: the "Symposium on the Effects of Waste Disposal on Kelp Communities" and an international symposium on remotely operated vehicles—"ROV '83."

Marine Bio-Optics Group

The University of California Marine Bio-Optics Group (UCMBO) is a new 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 is participating in three multiyear, multi-institutional research programs emphasizing theoretical and experimental marine bio-optics and remote sensing. The first program is the study of phytoplankton dynamics in the eutrophic coastal waters of California. A variety of data sources will provide a basis for increased understanding of production at high trophic levels. Second is the optical dynamics experiment, aimed at developing and investigating upper-mixed-layer hydrologic models linking physical, biological, and optical properties with respect to physical forcing functions such as winds and storms. In the third program, the warm core rings project, the processes associated with rings (anticyclonic mesoscale eddies that have separated from the Gulf Stream) and their environs will be investigated. Close coordination with NASA P3 aircraft flying a laser chlorophyll detecting system and with temperature and color satellite measurements demonstrated the effectiveness of multiplatform sampling strategies.

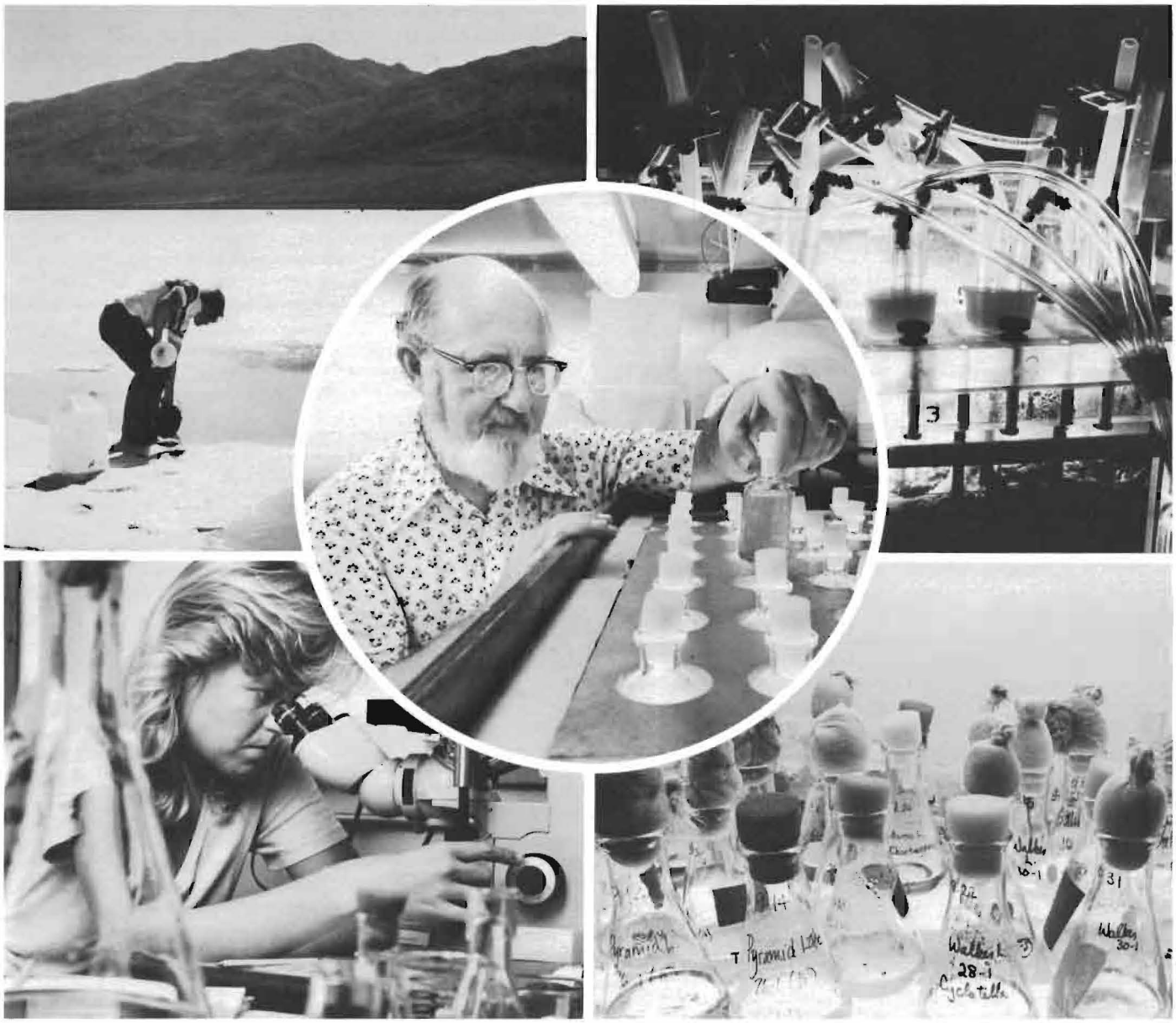
UCMBO scientists augmented six field expeditions with the design and construction of a unique bio-optical profiling system that allows for an expanded set of simultaneous shipboard measurements of optical, physical, and biological parameters. This instrument was developed to fill the need for multiplatform sampling techniques to study ocean processes occurring on various spatial and temporal scales.

Phytoplankton Resources Group

The Phytoplankton Resources Group, led by Dr. William H. Thomas, collected saline water samples from the deserts of eastern California and western Nevada. Salt-tolerant algae have been isolated from these waters and tested for their growth in artificial media. The best-growing algae have been selected for further experimentation on their temperature and salinity requirements. Best growth occurred at intermediate temperatures and salinities. The group is seeking strains of saline desert algae that might be cultured outdoors, using solar energy to produce high-energy products or protein.

California Sea Grant College Program

California's Sea Grant College Program, directed by Dr. James J. Sullivan, is headquartered on the Scripps campus. The program's purpose is to accelerate sound development of



W. H. THOMAS

L. D. FORD

Upper left: Peter M. Eldridge takes a sample of concentrated brine from the salt lake of eastern California's Saline Valley. Upper right: Algae samples undergo light test to find the perfect amount of light for the greatest production. Center: Dr. William H. Thomas checks bottles of algae undergoing temperature/salinity tests. Lower left: Ann Kelly checks algae production. Lower right: Algae samples in flasks await further tests.

marine resources by supporting a unique combination of marine research, education, and advisory activities throughout the state. This year 61 projects were supported at 19 California universities, colleges, and marine institutions. These projects cover fisheries aquaculture, coastal resources, new marine products, ocean technology, and marine affairs. Eighteen of these projects were carried out on the Scripps campus. Reports of all the projects are available from the Scripps Sea Grant office.

Polar Research Program

The functioning and dynamics of the Arctic and Antarctic marine food webs are the concern of the Scripps Polar Research Program. Under the leadership of program director Dr. Osmund Holm-Hansen, polar food-web problems are approached via biological and biochemical oceanography. Antarctic studies with ^{15}N-labeled nitrogenous substrates indicate that between 50% and 90% of all nitrogen assimilated by phytoplankton is in the form of ammonia, much of this occurring in the nanoplankton fraction. Temperature studies show that overall growth rates of phytoplankton communities are very low (less than one doubling per day) and correlated to the prevailing low temperatures. A doubling of the photosynthetic rate between 0° and 8°C was also found, above which there was a rapid decrease in carbon assimilation.

An Antarctic circumnavigation was completed during the 1983 winter. A cruise objective was to document the proportion of microphytoplankton versus nanophytoplankton in relation to water masses and sea ice. The biomass and trophic mode of three size categories of plankton were documented. In both ice-covered and open waters, the phytoplankton cells were smaller than expected and accounted for over half the biomass.

Drs. Holm-Hansen and Mark E. Huntley evaluated the food requirements of krill *(Euphausia superba)* as a function of its biomass (estimated by net and acoustic data) and life-cycle stages. The data on phytoplankton biomass and rate of primary production suggest that krill population growth during swarming may be limited by the available food supply.

Marine Natural Products Group

Scientists in the Marine Natural Products Group are focusing on the unique organic compounds produced by marine plants and animals. With the guidance of Dr. William H. Fenical, the group explores the biologically active and often toxic substances produced mainly by soft-bodied marine organisms as chemical defenses. Studies of the chemical adaptations of tropical reef plants and the development of several new anti-inflammatory metabolites from Caribbean sea whips and fans (gorgonian corals) are under way. (See Highlights section.)

Food Chain Research Group

Members of the Food Chain Research Group (FCRG) study the interactions of bacterioplankton, phytoplankton, and zooplankton with their environment. Research includes an evaluation of the effects of the physical/chemical environment on these organisms' distribution and activities. The vertical fluxes of organic matter in the sea are also being investigated, as is the transfer of energy between trophic levels.

As part of the group's project examining the fates of biogenic organic materials produced in the surface waters of the Southern California Bight, Dr. George A. Jackson is analyzing distribution of oxygen, nitrogen, salinity, and temperature around the southern sill of the Santa Monica-San Pedro Basin. Nitrogen and oxygen concentrations are lowered within the basin because of biological consumption. Data on distribution of these hydrographic properties are used to infer the flow field in the area, along with nitrogen and oxygen fluxes in the basin. Dr. Peter M. Williams found that the sum of free and combined amino acids plus combined carbohydrates in the Santa Monica Basin accounts for 15% of the total dissolved (plus colloidal) organic carbon in the upper 100 m and 6% in the deeper waters. Total amino acid nitrogen accounts for ~10% of the dissolved organic nitrogen in the entire water column. These percentages are higher in the "younger" waters most recently advected into the basins, and free amino acids increase below the sill depth during microbial denitrification. There are relatively few differences in amino acid composition between the free, combined, and particulate organic carbon pools, and these compositions do not change significantly with time or depth.

In two cruises to the San Pedro Basin area of the bight, Dr. Angelo F. Carlucci studied the microbiology of particle flux in the water column. Particles collected in Andrew Soutar's sediment traps contained about two orders of magnitude more bacteria than in the ambient water. In addition, high microbial activity was observed in the traps. Dr. Bess B. Ward, with Dr. Carlucci, initiated work on the microbiological nitrogen cycle in the sea. They evaluated the relative contribution of nitrifying bacteria and phytoplankton in the bight to the turnover of ammonium and nitrite, as well as their importance in the oceanic nitrogen cycle. Dr. John R. Beers and associates are studying the composition of sinking and suspended seston.

Dr. Jackson is also investigating kelp bed currents and ocean/human interactions. Analyses of data show that a large kelp bed has a much different current regime than a similar, kelp-free area. The implication is that a large kelp bed interacts only weakly with outside waters, and thus it becomes difficult for planktonic larvae to colonize the interior and difficult for sewage contaminants to settle there. Drs. Jackson and Williams are interpreting dissolved organic nitrogen (DON) distributions in the sea. DON, the largest pool of nitrogen in surface waters, may be an important part of near-surface nitrogen cycling and needs to be studied more intensively.

Dr. Williams and co-workers find that lipid-type materials are minor components of the natural sea-surface microlayer relative to the protein plus carbohydrate. No striking systemic differences in the organic chemical composition of microlayers are seen in samples collected in eutrophic and oligotrophic waters, in day versus night samples, or in coastal versus offshore samples. This indicates a ubiquitous source of surface-active organic matter for film formation in uncontaminated areas. Dr. Carlucci measured turnover rates of glutamic acid of <10 to >100 hours in the films. Turnover times were shorter in plankton-rich areas.

New conceptual models and observations of planktonic food webs in the central subtropical ocean suggest that much of the photosynthesis and respiratory metabolism is carried out by organisms smaller than 5-10 micrometers. Dr. Richard W. Eppley and colleagues from the United States and Canada met in Hawaii to determine if such organisms were abundant in Hawaiian coastal waters (they were) and to measure their metabolic rates. The work is part of the PRPOOS (Plankton Rate Processes in Oligotrophic Oceans) project, which is aimed at determining the rate of primary production in the central oceans. Program scientists are deciding whether the standard ^{14}C method gives acceptable results even when an entire food web, including plants, bacteria, and herbivores, is enclosed in the experimental bottles. The data suggest as much as 40% of the organic carbon produced by photosynthetic forms was found in bacteria and herbivores after 24 hours.

Dr. Farooq Azam is studying the role of bacterioplankton in the flux of matter and energy in pelagic marine food webs. Chemical dynamics during growth indicate a tight coupling between the production of bacterial nutrients and their utilization. Dr. Azam proposed a microenvironmental model to explain the rapid growth and consumption of free-living bacteria. Bacteria may, by chemotaxis and motility, cluster in the vicinity of the sources of bacterial nutrients (algae, decomposing particles) and take up the nutrients rapidly. This clustering may greatly accelerate the decomposition of organic matter, and provide a locale for intense predation on bacteria by microflagellates and ciliates. Predation on bacteria may maintain high concentrations of inorganic nutrients for rapid growth of algae within the microenvironment.

Drs. Timothy R. Jacobsen and Azam have focused on bacteria's role in the decomposition of *Calanus pacificus* fecal pellets, and how bacteria utilize amino acids and protein in seawater. Work to date suggests that bacteria rapidly use protein at rates greater than the utilization of free amino acids.

Dr. Holm-Hansen and Christopher D. Hewes developed a technique that permits quantitative microscopical analysis of small plankton. They use epifluorescence to distinguish between autotrophic and heterotrophic cells. The ratios of biomass between these different nutritional modes can vary greatly in local waters at different times of the year. This may partially explain discrepancies between biochemical estimates of phytoplankton stocks of natural populations as compared to laboratory cultures.

Drs. Beers and David C. Brownlee are studying the food and feeding of nonloricate oligotrichous ciliates. Preliminary results suggest that the ciliate studied may be better adapted to feeding on freely suspended food materials than on aggregated materials.

In a study carried out in Australia, Dr. Michael M. Mullin labeled phytoplankton and bacteria with different radioisotopes to measure the filtering rates of salpae in situ on these sources of food, and to see if the reported growth rates were sustainable by ambient concentrations of food. He completed a

cooperative project on the relation between the ratio of stable nitrogen isotopes in zooplankton and the relative importance of nitrate and ammonium as nitrogen sources for the phytoplankton on which the zooplankton feed. Elaine R. Brooks determined the vertical patterns of distribution of zooplanktonic biomass and of several species in the Southern California Bight. She did this as a preface to estimating the role of zooplankton in the vertical flux of organic matter in the deep basins of the southern California borderland. A study of the relationship between the intensity and pattern of small-scale patchiness in coastal zooplankton and the large-scale, interannual changes associated with the El Niño was initiated.

Nearshore Research Group

Studies on wave climatology and nearshore sediment transport continued in the Nearshore Research Group, under the direction of Dr. Richard J. Seymour.

Meredith H. Sessions directed the installation of five directional wave measurement arrays in the reach from Imperial Beach to San Clemente, California, to begin a four-year study of the local wave climate and its effects on shoreline erosion and sediment transport. The coastal wave network facilities were also employed to study wave and current climates within San Francisco Bay.

Other studies include episodicity in longshore transport based upon multiyear measurements of wave direction from a number of locations and the mechanisms of cusp formation and destruction on sandy beaches. Longshore sediment transport studies based upon a trap experiment at Santa Barbara, California, and the use of a hydrostatic profiler to measure changes in beach morphology are also being investigated.

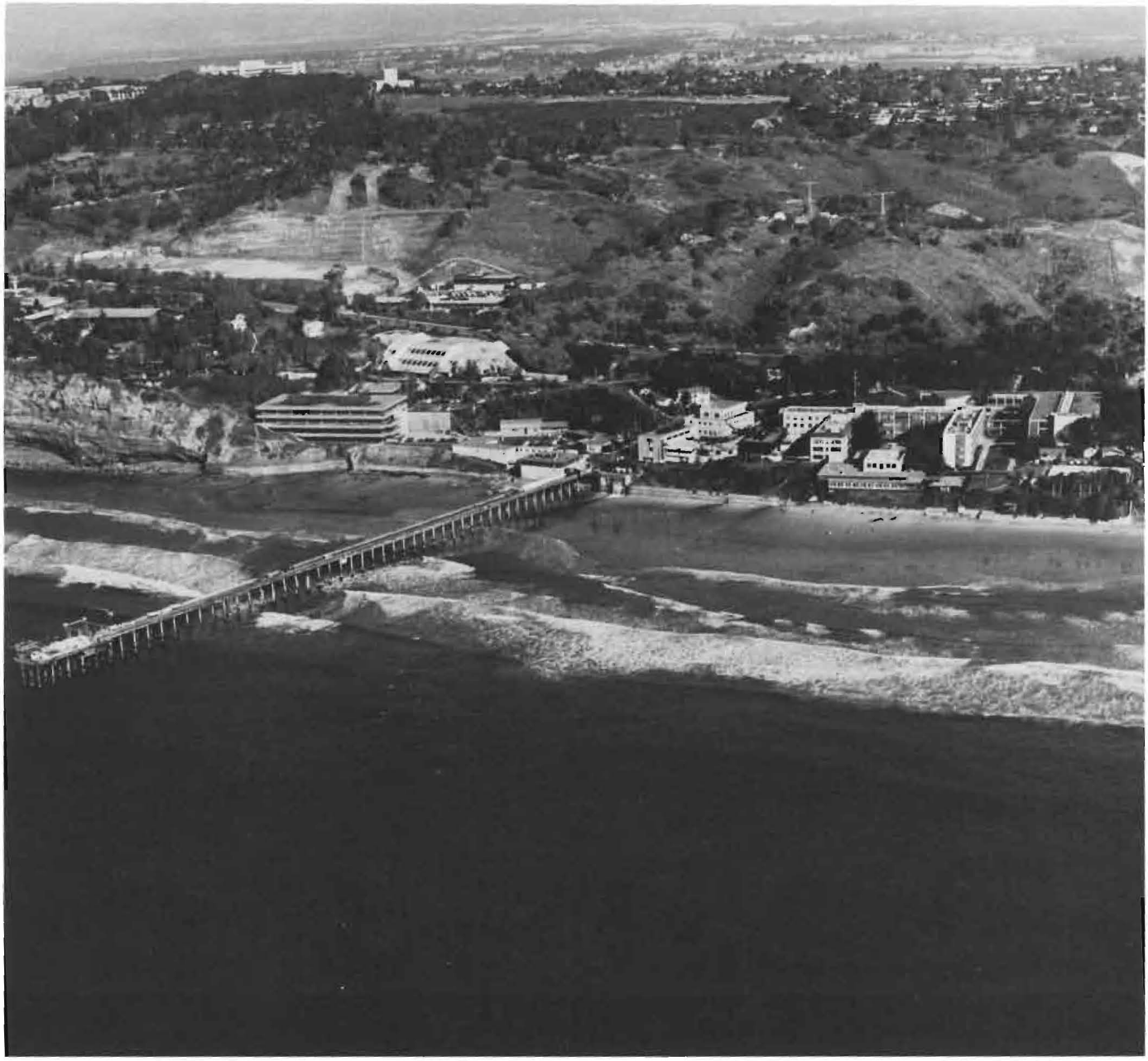
Other IMR Research Activities

Dr. Mizuki Tsuchiya is studying upper ocean circulation with emphasis on formation and circulation of the 13°C water in the equatorial Atlantic, the 18°C water in the North Atlantic, and the Subantarctic Mode Water in the South Atlantic. Both lateral and vertical mixing are important in determining the properties of these water masses, each of which is characterized by a well-developed thermostad (a layer in which the vertical gradient of temperature is relatively small) in nearly the same density range. Maps of geostrophic flow and various water characteristics have been prepared for three uniformly dense surfaces. The maps show that the circulation consists basically of the subtropical anticyclonic gyres in both hemispheres and the alternating eastward and westward zonal flows in low latitudes. No direct connection is found between the thermostads of the three water masses studied.

Dr. Tsuchiya also analyzed nutrient data collected to the east of the Galápagos Islands and showed that nutrient concentrations are useful parameters for monitoring the Equatorial Undercurrent.

Sargun A. Tont is verifying the statistical correlations between temporal changes in phytoplankton abundance and climatological variables for several new locations. He also studied the alongshore coherence of the same variables.

R/V Ellen B. Scripps *departs on a cruise.*



B. CALL

An aerial view of Scripps Institution of Oceanography

SEAGOING OPERATIONS

R/V *New Horizon*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
7/4-7/26/82		North of Hawaii to 30°N	Measurements of temp., conductivity, current	Honolulu	L. Regier/P. Niiler, D. Caldwell, C. Paulson (OSU)	T. Desjardins
7/30-8/30/82	SOSO	Eastern Pacific	Bio., physical, chem. properties on transect	San Diego	L. Haury	L. Davis
9/12-10/11/82	WASP	Santa Barbara Basin	Midwater bio. studies	Port Hueneme, San Diego	B. Robison (UCSB)	T. Desjardins
10/12-10/25/82		San Clemente Basin, San Juan Seamount	Physiological studies	Port Hueneme, San Diego	J. Childress (UCSB)	T. Desjardins
11/2-11/12/82	SF-4	West coast of Baja, Calif.	Sea-surface film studies	San Diego	P. Williams	T. Desjardins
11/17-11/21/82	SCBS-21	Southern Calif. Bight	Biological studies	Dana Pt., San Diego	R. Eppley/J. Beers	T. Desjardins
3/30-5/12/83	OPUS	Point Conception	Field effort of OPUS project	Wilmington, San Diego	B. Jones (USC)/ K. Brink (WHOI)	L. Davis
5/16-5/25/83	SCBS-22	Southern Calif. Bight	Microbiology	San Diego	A. Carlucci	T. Desjardins
5/31-6/30/83		Santa Catalina Basin, Patton Escarp. & points en route to Honolulu	Benthic boundary layer studies, zooplankton population studies	Honolulu	K. Smith/ E. Lange	T. Desjardins

TOTAL DISTANCE STEAMED: 35,482 nautical miles OPERATING DAYS: 179

R/V *Melville*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
6/18-7/21/82	MAGMA 1	East Pacific Rise	Deploy./recovery of OBSs	San Diego	J. Orcutt	R. Haines
7/22-7/23/82	MANOP	San Clemente Basin	Benthic flux measurements	San Diego	R. Weiss	R. Haines
9/27-9/29/82	MANOP	San Clemente Basin	Benthic flux measurements	San Diego	R. Weiss	R. Haines
10/4-10/26/82	Benthic 1	North of Hawaii	Argon-39 profile	Hilo, Honolulu	H. Craig	R. Haines
10/29-11/28/82	Benthic 2	Musician Seamounts, Line Islands area	Benthic boundary layer energetics of seamounts	Honolulu	K. Smith	R. Haines
12/2-12/29/82	Benthic 3	140°W, 11°N; 139°W, 1°N	MANOP lander deployment	Honolulu	R. Weiss	A. Arsenault
1/9-2/16/83	Benthic 4	East of Tonga Trench	Deploy marine seismic system	Papeete	T. Jordan/ J. Orcutt	R. Haines
2/19-3/13/83	Benthic 5	Along Equator between 150°W and 130°W	Recover moorings	Papeete	C. Eriksen (MIT)	R. Haines
3/17-4/5/83	Benthic 6	East of Tonga Trench	Recover marine seismic system	Papeete	T. Jordan/ J. Orcutt	R. Haines
4/8-4/25/83	Benthic 7	Mehetia Seamount	Argon-39 samples	Hiva Oa, Nuku Hiva	H. Craig	W. Stow
4/26-5/11/83	Benthic 8	Marquesas Is., East Pac.	Water sampling	San Diego	J. Bullister	W. Stow
6/5-6/28/83	Echo 1	About 15°N, 118°W	Deep Tow survey	San Diego	F. Spiess	R. Haines

TOTAL DISTANCE STEAMED: 28,765 nautical miles OPERATING DAYS: 257

R/P FLIP

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
7/16-7/19/82		Local	Equipment test	San Diego	J. Simpson	D. Efird
8/17-9/1/82		Local	Resource assessment	San Diego	J. Yoder (SAI)	D. Efird
9/22-9/29/82		Local	Ocean dynamics	San Diego	R. Pinkel	D. Efird
10/6-11/18/82		Northeast Pacific	Ocean optics	San Diego	J. Simpson	D. Efird
12/10-12/17/82		Local	MILDEX equip. test	San Diego	R. Weller (WHOI)	D. Efird
1/31-2/3/83		Local	Array tests	San Diego	R. Williams	D. Efird
5/11-5/20/83		Local	MILDEX equip. test	San Diego	R. Pinkel	D. Efird

OPERATING DAYS: 94

R/V *Ellen B. Scripps*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
6/9-7/6/82		Pacific Northwest	Seal census	San Diego, Santa Cruz, Seattle, Port Angeles, San Diego	B. Le Boeuf (UCSC)	T. Beattie
7/13-7/23/82		Santa Barbara Channel	Seismic studies	San Diego, Santa Barbara, San Diego	W. Prothero (UCSB)	T. Beattie
7/24/82		San Diego Trough	Student cruise	San Diego	R. Dunbar	T. Beattie
8/23-8/26/82		Southern Calif. Bight	Electric measurements	San Diego	C. Cox	T. Beattie
9/23-9/24/82		San Diego Trough	Equipment tests	San Diego	J. Simpson	T. Beattie
10/25-10/29/82		Southern Calif. Bight	Electric measurements	San Diego	C. Cox	T. Beattie
10/30/82		San Diego Trough	Student cruise	San Diego	R. Rosenblatt	T. Beattie
11/15-11/18/82		Southern Calif. Bight	Recover equipment	San Diego	C. Cox	T. Beattie
12/15-12/21/82		San Diego–Santa Barbara	Near surface oceanography	San Diego	E. Lange	T. Beattie
1/20/83		Oceanside/San Clemente	Current measurements	San Diego	A. Bratkovich	T. Beattie
1/31-2/3/83		Southern Calif. Bight	Equipment tests	San Diego	C. Cox	T. Beattie
2/9-2/10/83		Southern Calif. Bight	Water sampling	San Diego	F. Azam	T. Beattie
2/13-2/24/83		North to central Calif.	Radiotracking seals	San Diego, Santa Cruz, San Diego	B. Le Boeuf (UCSC)	T. Beattie
3/9/83	Aztec X	CalCOFI station 94.32	Student cruise	San Diego	D. Dexter (SDSU)	T. Beattie
3/11-3/12/83	Bottom Snapper	Santa Catalina Basin	Deploy deep-sea camera	San Diego	C. Smith	T. Beattie
3/15-3/16/83		Southern Calif. Bight	Microplankton sampling	San Diego	J. Beers	T. Beattie
3/17-3/19/83		Southern Calif. Bight	El Niño studies	San Diego	W. Bryan	T. Beattie
3/23-5/3/83		Costa Rica Rift area	Seismic work w/*Glomar Challenger*	San Diego	R. Stephen (WHOI)	T. Beattie
5/6-5/8/83		Santa Catalina Basin, off Oceanside	Recover deep-sea camera, shelf current studies	San Diego	C. Smith/ A. Bratkovich	T. Beattie
5/11-5/14/83		Southern Calif. Bight	El Niño studies	San Diego	W. Bryan	T. Beattie
5/17-5/24/83		Calif. coastal waters	Thermosalinigraph measurements	San Diego	L. Armi	T. Beattie
5/31/83		San Diego Trough	Student cruise	San Diego	M. Mullin	T. Beattie
6/3-6/9/83		Southern Calif. Bight	Equipment tests	San Diego	C. Cox	T. Beattie
6/11/83		San Diego Trough	Student cruise	San Diego	R. Rosenblatt	T. Beattie
6/13-6/16/83		Southern Calif. Bight	El Niño studies	San Diego	W. Bryan	T. Beattie
6/24-7/7/83		California islands	Sea lion studies	San Diego	B. Le Boeuf (UCSC)	T. Beattie

TOTAL DISTANCE STEAMED: 12,305 nautical miles OPERATING DAYS: 143

R/V *Thomas Washington*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
7/8-8/8/82	CERES 2	Orozco Fault Zone	Sea Beam investigation	San Diego, Cabo San Lucas, Acapulco	J. Mammerickx/ K. Macdonald (UCSB)	A. Arsenault
8/12-9/11/82	CERES 3	Panama Basin	Sea Beam surveying	Acapulco, Balboa	P. Lonsdale/ R. Batiza (WU)	C. Johnson
9/15-10/26/82	CERES 4	Cocos-Nazca spreading center	Sea Beam, magnetics, Deep Tow	Balboa, San Diego	R. Hey/R. Tyce	C. Johnson
1/4-2/1/83	PASCUA 1	East Pacific Rise	Sea Beam and Seamarc use	San Diego, Manzanillo	P. Fox (URI)/ W. Ryan D. Fornari (LDGO)	L. Davis
2/6-2/27/83	PASCUA 2	Garrett Transform	Sea Beam surveying	Manzanillo, Easter Island	P. Fox (URI)	C. Johnson
3/3-3/28/83	PASCUA 3	East Pacific Rise	Sea Beam survey of vents	Easter Island	H. Craig	C. Johnson
4/1-4/30/83	PASCUA 4	East Pacific Rise	Sea Beam, magnetic anomaly survey	Easter Island, Callao	R. Hey	C. Johnson
5/4-5/26/83	PASCUA 5	East Pacific Rise	Sea Beam, acoustic backscatter measurements	Callao, San Diego	C. de Moustier/ P. Lonsdale	C. Johnson
6/13/83		San Diego Trough	Equipment tests	San Diego	M. Mullin	C. Johnson
6/17-6/27/83		Seamounts west of San Diego	Sea Beam surveying/OBS	San Diego	P. Lonsdale/ L. Dorman	C. Johnson

TOTAL DISTANCE STEAMED: 49,496 nautical miles OPERATING DAYS: 266

R/P ORB

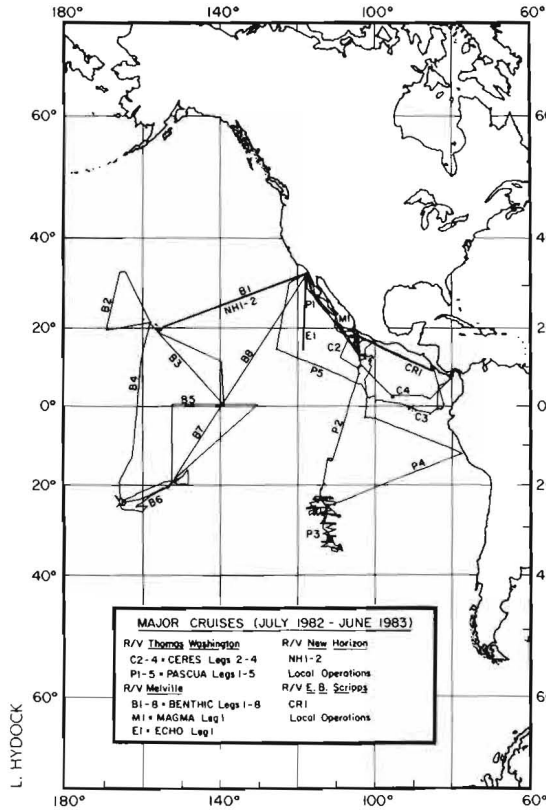
DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
10/18-10/22/82		Local	Instrument tests	San Diego	R. Williams	T. Hoopes
4/11-4/14/83		Local	Thrust tests	San Diego	V. Anderson	T. Hoopes

OPERATING DAYS: 9

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**	19	10	10

1982-83 Total operating days: 948 1982-83 Total nautical miles steamed: 126,048 *Depends on towing vessel **With berthing vans



Track chart

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 are provided a substantial education in oceanography, and oceanographers receive training in modern engineering. The 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) to understand 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 places particular emphasis on 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 sea floor. Research programs are based on the interactions of the components of seawater 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 paleoceanography, petrology, geochemistry, and cosmochemistry. Expedition work at sea, and field work on land are emphasized as an essential complement to laboratory and theoretical studies.

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

GRADUATE STUDENTS AND DEGREE RECIPIENTS

In the fall of 1982, 40 new students were admitted to graduate study. Of these, 10 were in marine biology, 6 in geological sciences, 2 in marine chemistry, 7 in geophysics, 5 in physical oceanography, 4 in applied ocean sciences, and 6 in biological oceanography. Enrollment at the beginning of the academic year was 198. Eleven Master of Science degrees and 33 Doctor of Philosophy degrees were awarded by UC San Diego to the students listed below.

Dr. Miriam Kastner gives a lecture on sedimentary petrology.

L. D. FORD

Doctor of Philosophy Degrees Awarded, with Titles of Dissertations

Earth Sciences

Marilee Henry, "A New Method for Slant Stacking Refraction Data and Some Applications."

Arthur L. Lerner-Lam, "Linearized Estimation of Higher-Mode Surface Wave Dispersion."

Char-Shine Liu, "Geophysical Studies of the Northeastern Indian Ocean."

Luis Manguía-Orozco, "Strong Ground Motion and Source Mechanism Studies for Earthquakes in the Northern Baja California–Southern California Region."

Sally Newman, "^{230}Th–^{238}U Disequilibrium Systematics in Young Volcanic Rocks."

Loren Shure, "Modern Mathematical Methods in Geomagnetism."

Marine Biology

Merrill J. Allen, "Functional Structure of Soft-Bottom Fish Communities of the Southern California Shelf."

Daniel H. Cohn, "Isolation, Organization, and Expression of the Luciferase Genes from *Vibrio harveyi*."

A. Peter Klimley, "Social Organization of Schools of the Scalloped Hammerhead Shark, *Sphyrna lewini* (Griffith and Smith), in the Gulf of California."

Gary W. Lopez, "Population Studies on *Tisbe cucumariae* (Copepoda: Harpacticoida)."

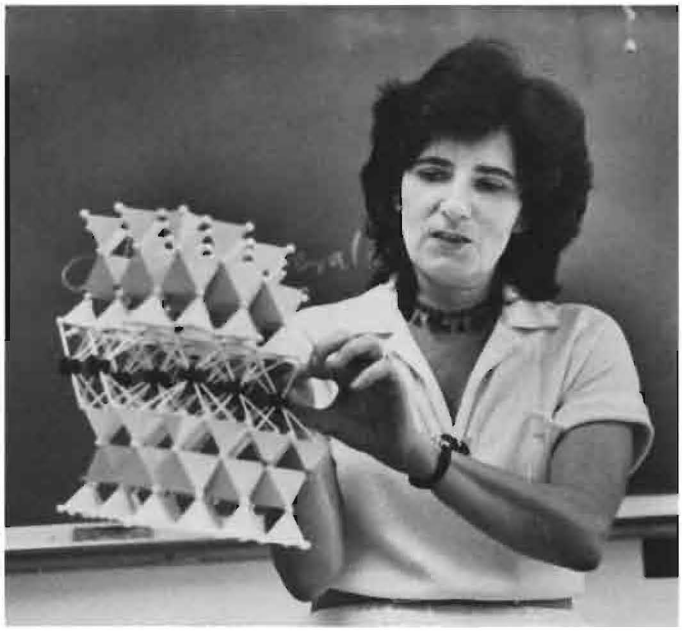
John H. Meyer, "Steroid Influences upon the Electric Organ Discharges of Weakly Electric Fishes: Sensory and Motor Considerations."

Kathleen M. Sullivan, "Bioenergetics of the Sablefish *Anoplopoma fimbria* Occurring off Southern California: A Hypothesis for Energetics of Low-Frequency Feeding in Deep-Living Benthopelagic Fishes."

Bradley M. Tebo, "The Ecology and Ultrastructure of Marine Manganese Oxidizing Bacteria."

Oceanography

Maury M. Bandurraga, "Natural Product Studies of Selected East Pacific Gorgonians."



Dave Broutman, "The Interaction of Short-Wavelength Internal Waves with a Background Current."

David J. Burdige, "The Biogeochemistry of Manganese Redox Reactions: Rates and Mechanisms."

Siu C. Cheung, "Interactions of Two Sine-Gordon Solitons in Two Dimensions."

M. Rustin Erdman, "Bottom Pressure Observations on the Continental Shelf."

Daniel M. Hanes, "Studies on the Mechanics of Rapidly Flowing Granular-Fluid Materials."

Rachel M. Haymon, "Hydrothermal Deposition on the East Pacific Rise at 21° N."

Michael J. Head, "The Use of Miniature Four-Electrode Conductivity Probes for High Resolution Measurement of Turbulent Density or Temperature Variations in Salt-Stratified Water Flows."

Sarah G. Horrigan, "Biological Processes Affecting the Distribution of Nitrogen in the Marine Environment: Contributions by Phytoplankton and Nitrifying Bacteria."

Shirley Imsand, "Abundance in Space and Time of Lanternfishes of the Genus *Triphoturus* (Myctophidae) in the Pacific Ocean."

Douglas B. Kent, "On the Surface Chemical Properties of Synthetic and Biogenic Amorphous Silica."

Kyung-Ryul Kim, "Methane and Radioactive Isotopes in Submarine Hydrothermal Systems."

Dong Soo Lee, "Bismuth, Nickel, and Palladium in Northeast Pacific Waters—Novel Analytical Methods in Marine Chemistry."

Lisa A. Levin, "The Roles of Life History, Dispersal and Interference Competition in the Population and Community Structure of a Dense Infaunal Polychaete Assemblage."

Sally A. Look, "Studies of the Natural Products Chemistry of Selected Caribbean Gorgonians."

José L. Ochoa de la Torre, "On the Two Limiting Types of Oceanic Finestructures."

Christine Provost, "A Variational Inverse Method for Estimating the General Circulation in the Ocean."

Kenneth E. Richter, "Development and Use of a 1.2 MHz Acoustic System to Examine Individual Zooplankton, and Small-Scale Zooplankton Distributions."

Spencer M. Steinberg, "The Geochemistry of α-Keto Acids and Oxalic Acid; The Chemical Decomposition Reactions of Proteins in Calcareous Fossils and Their Effect on Amino Acid Based Geochronological Methods."

Daniel O. Suman, "Agricultural Burning in Panama and Central America: Burning Parameters and the Coastal Sedimentary Record."

Master of Science Degrees

Earth Sciences

Raul R. Castro
Christopher V. Metzler
Patricia A. Schultejann
Scott H. Stevens

Marine Biology

Teodora Bagarinao
John L. Hakanson

Oceanography

Timothy J. Bralower
Susan K. Mathews
Lorraine A. Remer
Juan A. Rodriquez-Sero
Paul S. Rosenzweig

SHORE FACILITIES AND SPECIAL 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 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 Balzers 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.

Cardiovascular Research Facility. This shared facility of 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 a cardiovascular instrumentation development laboratory.

Diving Facility. The 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.

Experimental Aquarium. Used by faculty, research staff, and graduate students for studies of living plants and animals, the experimental aquarium is provided with ambient and chilled seawater, and is equipped with 5 rooms for controlled environmental studies, 20 tanks, and 9 seawater tables.

Hydraulics Laboratory. This laboratory has a wind-wave channel 43x2.4x2.4 m in size with a tow cart for instrument and model towing; a two-layer stratified flow channel, test section 1.1x1.1x16m; 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; and an insulated, refrigerated, cylindrical seawater tank 10 m deep and 3 m in diameter. All wave generators in the laboratory incorporate servo systems and can be computer or magnetic-tape controlled. 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.

Marine Science Development and Outfitting Shop. This shop is equipped with precision tools and machinery. A staff of toolmakers and diemakers designs, develops, and fabricates research equipment and instrumentation in support of the various laboratories at Scripps and other educational and governmental organizations throughout the United States.

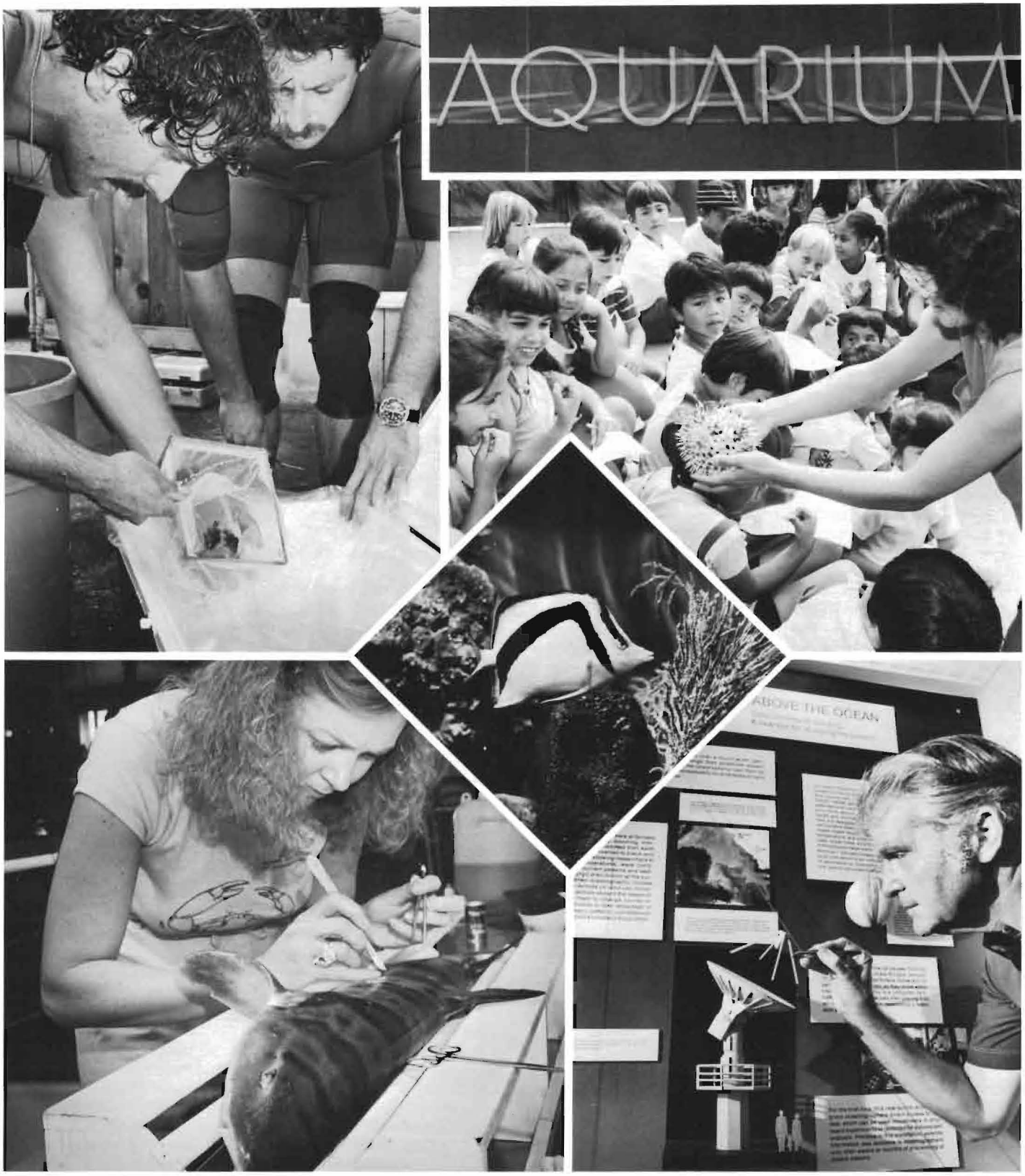
Mass Spectrographic Equipment. Nine mass spectrometers are available: they include two 15-cm, Nier-type spectrometers, and one 6-cm Micromass instrument for isotopic analysis of light elements; a 15-cm, Nier-type spectrometer for rare gases; a 25.4-cm double-collection mass spectrometer for He^3/He^4 ratio measurements; a 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 spectometer 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 using 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 available at cost to qualified users. The more sophisticated or costly equipment is available 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 4 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 radiocarbon or other isotopic sample acquisition. A large winch holding 10,000 m of conducting wire is operated by PACODF on expeditions where 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 inventory 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. Tape drives, plotters, and printers are in use with both seagoing and shore-based systems.



L. D. FORD

Upper left: John B. O'Sullivan and Bruce A. Blumer transfer newly collected fish into chest for trip to San Francisco's Steinhart Aquarium. Upper right: Aquarium docent shows a porcupine fish to second-grade children. Center: Chaetodon falcifer, *a scythe butterfly fish in one of the fish tanks on display at the aquarium. Lower left: Dr. Julie Glowacki, from Children's Hospital in Boston, prepares to implant demineralized bone powder in an anesthetized leopard shark. This research, being done at Scripps Aquarium, may advance current techniques in bone transplants in humans. Lower right: Robert D. Mason repairs the satellite oceanography exhibit in the museum.*

Physiological Research Laboratory Pool Facility. This facility includes a holding pool for large marine mammals and fish; a ring pool of 10-m radius equipped with a variable-speed trolley to carry instruments for various hydrodynamic and biological studies of man and other mammals; and a behavioral pool for echolocation studies and animal training. A central island within the ring pool contains small, dry laboratories and a "wet" laboratory equipped to handle large animals. A flow 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 communications services worldwide to Scripps, NMFS, and other governmental and institutional 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 40 m of water and offers 1,372 m of unobstructed range.

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. The 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 nearly 3,400 serial titles and has a cataloged collection of 140,000 volumes, as well as an extensive documents, reports, and translations collection, a maps and charts collection emphasizing nautical information, and a rare book collection with numerous accounts and journals of famous voyages of discovery.

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 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 in 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 two high-speed sand filters and two concrete storage tanks with a total capacity of 439,060ℓ. Delivery capacity is 5,300ℓ per minute.

Shipboard Computer Group. This group of computer programers, engineers, and technicians supports four IBM 1800 computers and, as required, other computer systems at Scripps through programing, interface design, and maintenance. Computers are installed permanently on R/V *Thomas Washington* and R/V *Melville* and on campus. The IBM 1800 computer systems are interfaced to ship's course and speed and to satellite navigation receivers for precise determination of data location. Scientific instruments interfaced to the computer for automatic data acquisition and storage include XBT (expendable bathythermography), magnetometer, transponder-ranging inputs for the Marine Physical Laboratory's Deep Tow vehicle, radio-relayed sonobuoy wide-angle reflection signals, and the R/V *Thomas Washington* Sea Beam system.

Digital seismic-reflection systems are available to sample one or more analog signals and record them on digital magnetic tape.

A Prime 750 computer system on campus is well adapted to economical number-crunching with a 3.2μs floating point (64 bits) multiplier, three megabytes of memory, 900 megabytes of disk, and an array processor. Its use is primarily by CRT terminals.

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 university scientists with living specimens.

This year more than 25,000 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 2.5 km 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 at this location. Navigation, depth, and magnetic 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 one 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 up to the current month 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.

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 1983. 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. 117p. 1981.

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). 68p. 1983.

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 atlas issued this year 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 1982 volume and may also be found in the publications cited. Information about a specific reprint can be obtained by writing directly to the author in care of: Scripps Institution of Oceanography, La Jolla, California 92093.

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G. G. KUHN

Storm damage on a beach in Carlsbad, north San Diego County

G. G. KUHN

Winter storm damage along the coast at Solana Beach in north San Diego County

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82-32 **Kuhns,** Kittie K. Bibliography of the Scripps Institution of Oceanography Reference Series 1982. August 1983. 7p.

Sea Grant Educational Series

The *California Sea Grant Educational Series* includes in-depth educational reports on marine topics of importance to California. It also includes newsletters, leaflets, and audiovisual materials. The publications listed below can be obtained by writing the California Sea Grant College Program, A-032, University of California, San Diego, La Jolla, California 92093.

E-003 **Zedler,** Joy B. Salt marsh vegetation: examples from the Tijuana Estuary. Sea Grant Publication Number E-CSGCP-003. 1983. 36p.

Sea Grant Marine Advisory Program Series

The Sea Grant Marine Advisory Program Series includes booklets, brochures, papers, and other publications produced by the Sea Grant Marine Advisory Program at the University of California, Davis. Copies of the publications listed below can be obtained by writing Sea Grant MAP Extension, University of California, Davis, California 95616.

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Price, Robert J. *Paralytic Shellfish Poisoning and Red Tides.* California Sea Grant Marine Advisory Program Leaflet Number 21117, Division of Agricultural Sciences, University of California. May 1983. 2p.

Toole, Christopher, Bruce B. **Wyatt** and Evelyn A. **Wunderlich.** *Cleaning, Cooking and Canning Albacore Tuna.* Sea Grant Marine Advisory Program Publication. June 1983. 8p.

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R-009 **Iles,** Amanda and Kelly E. **Anderson.** California Sea Grant 1982-83 program directory: making waves. Sea Grant Publication Number R-CSGCP-009. 1982. 29p.

R-010 **Anderson,** Kelly E. (editor). Making waves, 5-year report: 1977-82, California's Sea Grant Program. Sea Grant Publication Number R-CSGCP-010. 1983. 75p.

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The California Sea Grant Technical Series includes reprints of journal articles, professional papers, scientific and technical reports, instructive manuals, and public policy papers resulting from Sea Grant-sponsored research. The publications listed below can be obtained by writing the California Sea Grant College Program, A-032, University of California, San Diego, La Jolla, California 92093.

T-006 **Luyendyk,** Bruce P., Earl J. **Hajic,** Robert E. **Crippen** and David S. **Simonett.** Side-scan sonar and high-resolution reflection maps of the Santa Barbara Channel seafloor. Sea Grant Publication Number T-CSGCP-006. 1983. 17p. + 7 maps.

T-007 **Josselyn,** Michael (editor). Wetland restoration and enhancement in California. A proceedings of a workshop held in February 1982, California State University, Hayward. Sea Grant Report Number T-CSGCP-007. 1982. 110p.

T-008 **Anderson,** Kelly E. (editor). Recent innovations in cultivation of Pacific molluscs: abstracts from the international symposium, December 1-3, 1982. Report Number T-CSGCP-008. 1983. 31p.

A conference cottage, left, was named the "Martin Johnson House" to honor Dr. Martin W. Johnson on his 89th birthday, September 30, 1982. Dr. Johnson is shown at work in his laboratory a few years ago.

STAFF

July 1, 1982, to June 30, 1983

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

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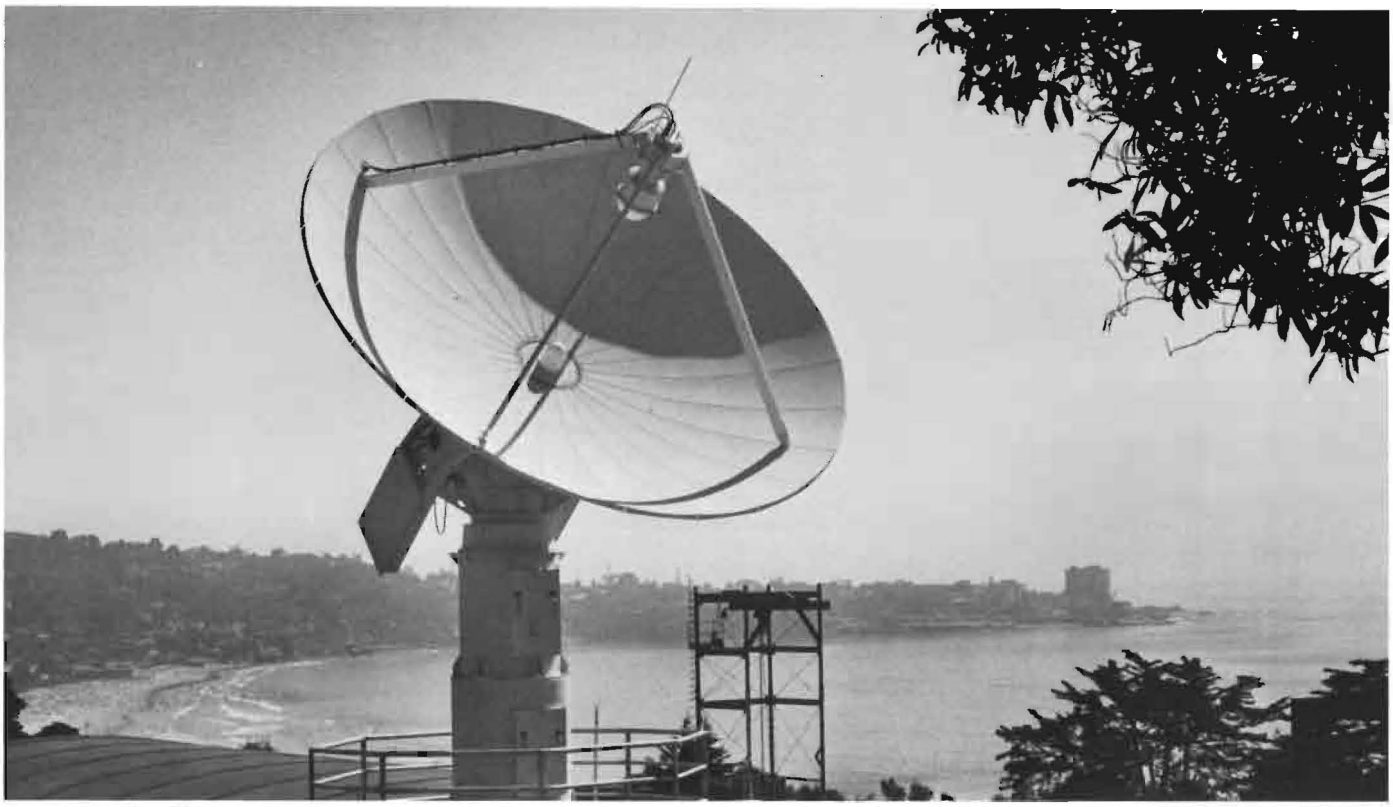


Scripps Satellite Oceanography Facility

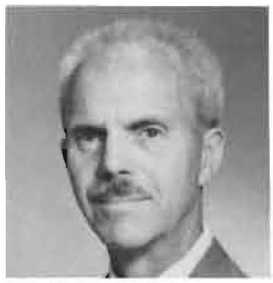
In Memoriam

Ben T. Cox. November 22, 1982. He was an aquarist at the aquarium-museum from 1951 until his retirement in 1975.

Ralph T. Hebden. February 10, 1983. He was in the publications and illustrations section of the Marine Life Research Group from 1961 to his retirement in 1971.

Thomas Alonzo Manar. August 26, 1982. He was the public information officer at Scripps from 1951 until the early 1960s.

Norris Watson Rakestraw. December 3, 1982. He was a professor of chemistry at Scripps from 1946 to his retirement in 1965. He established a program in marine chemistry at the institution; he edited the *Journal of Chemical Education* for 15 years; and he served as the first dean of the graduate division at UC San Diego from 1961 to 1965.



Dr. Norris W. Rakestraw

Gilbert R. Van Dyke III. November 19, 1982. He had been a graduate student in the Applied Ocean Sciences curricular group at Scripps since 1973.

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William J. Goff

MARINE SCIENCE DEVELOPMENT AND OUTFITTING SHOP
Harold H. Hill

PUBLIC AFFAIRS
Jacqueline L. Parker

TECHNICAL PUBLICATIONS
Kittie K. Kuhns

*Also Vice Chancellor of Marine Sciences and Dean of Marine Science
†Current June 30, 1983

APPENDIX B*

Sources of Financial Support

State and Federal Agencies

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

United States
Commerce, Department of
National Bureau of Standards
National Oceanic and Atmospheric Administration
Defense, Department of
Air Force
Army, Department of the
Army Corps of Engineers
Defense Mapping Agency
Navy, Department of the
Naval Ocean Systems Center
Naval Sea Systems Command
Office of Naval Research
Energy, Department of
Environmental Protection Agency
Health and Human Services, Department of
National Institutes of Health
Interior, Department of the
U.S. Geological Survey
National Aeronautics and Space Administration
National Science Foundation

Foundations/Corporations/ Organizations

Amax Foundation, Inc.
AGIP Petroleum Company
American Pacific Inflatable Boats, Inc.
American Society for Engineering Education
AMOCO Production Company
ARCS Foundation, Inc.
Stephen & Mary Birch Foundation, Inc.
Cities Service Company
Marcel Dekker, Inc.
Donors of the Petroleum Research Fund
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Elsevier Scientific Publishing Company
Evans & Sutherland
EXXON Production Research Company
Foundation for Ocean Research
Cecil H. and Ida Green Foundation
Intersea Research Corporation
W. M. Keck Foundation
La Jolla Foundation for Earth Sciences
John D. & Catherine T. MacArthur Foundation
Ocean Mining Associates
Plastic Surgery Research Foundation
R. P. Foundation
Josephine Stedem Scripps Foundation
Francis P. Shepard Foundation
Seth Sprague Educational & Charitable Foundation
The Tinker Foundation, Inc.
University Research Foundation

Scripps Industrial Associates
AMOCO Oil Company
ARCO Oil and Gas Company
British Petroleum Development, Ltd.
Cities Service Oil Company
EXXON Production Research Company
Getty Oil Company
Gulf Oil Company
Japan Petroleum Exploration Company
Mobil Oil Company
Ocean Minerals Company
Phillips Petroleum Company
Shell Oil Company
Société Nationale Elf Aquitaine (Production)
Standard Oil Company of California
Superior Oil Company
Texaco, Inc.
Union Oil Company of California

Individuals

Dr. Victor C. Anderson
Dr. Gustaf O. S. Arrhenius
Dr. James R. Arnold
Dr. Robert Siple Arthur
Dr. Roswell W. and Patricia Austin
Thomas T. Beattie, Jr.
Capt. Charles B. Bishop
Dr. Theodore H. Bullock
Estate of Nina Button
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Dr. George G. and Betty Shor
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Dr. George N. Somero
Dr. Fred N. and Sally Spiess
Payson R. Stevens
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Dr. Victor D. Vacquier
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Dr. Kenneth M. Watson
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Capt. James G. Williams III
George S. Winterbotham
Dr. Edward L. Winterer
David Wirth

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

APPENDIX C

Major Awards and Honors

Dr. Harmon Craig
Elected a Fellow of the American Geophysical Union.
Dr. J. Freeman Gilbert
Elected an honorary Foreign Fellow of the European Union of Geosciences.
Dr. Thomas H. Jordan
Received the James B. Macelwane Award from the American Geophysical Union.
Elected a Fellow of the American Geophysical Union.
Dr. Walter H. Munk
Named an associate of the Royal Astronomical Society.
Dr. Jerome Namias
Elected to membership in the National Academy of Sciences.
Named a Fellow of the American Academy of Arts and Sciences.

Dr. William A. Nierenberg
Nominated by President Reagan to the National Science Board.
Elected to the National Academy of Engineering.
Dr. Roger R. Revelle
Received honorary Doctor of Science degree from the University of Miami, Florida.
Dr. Fred N. Spiess
Received the Maurice Ewing Medal from the U.S. Navy and the American Geophysical Union.
Elected a Fellow of the American Geophysical Union.
Dr. Victor D. Vacquier
Elected a Fellow of the American Association for the Advancement of Science.
Dr. Fred N. White
Elected a Fellow of the American Association for the Advancement of Science.

APPENDIX D

The Regents of the University of California

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Leo McCarthy
Lieutenant Governor of California
Willie L. Brown, Jr.
Speaker of the Assembly
William Honig
State Superintendent of Public Instruction
James N. Thayer
President of the Alumni Association of the University of California
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Vice President of the Alumni Association of the University of California
David Pierpont Gardner
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Owsley B. Hammond
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Thomas J. Cunningham
Associate Counsel of the Regents, Emeritus
John E. Landon

Docent explains tide-pool life to visitors at the Scripps Aquarium Museum.

B. CALL

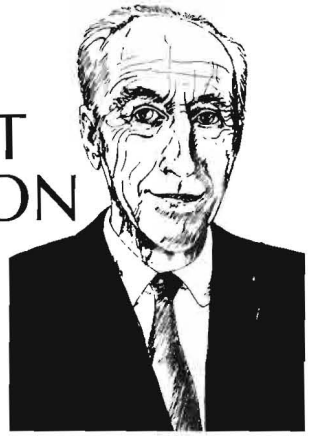
APPENDIX E

Current Funds Expenditures 1982-1983

INSTITUTES

Agency	Scripps Institution of Oceanography	Geophysics and Planetary Physics	Marine Resources	Cal Space	Total	Percentage of Total
FEDERAL GOVERNMENT						
National Science Foundation	$34,680.634	940,114	600,683	47,383	36,268,814	55.8
Navy, Department of the	8,520,369	397,044	8,436	—	8,925,849	13.7
National Aeronautics and Space Administration	243,740	54,381	73,098	132,924	504,143	.8
Army, Department of the	(1,273)	—	640,529	—	639,256	1.0
Energy, Department of	451,469	—	397,630	—	849,099	1.3
Air Force, Department of the	759,294	—	—	—	759,294	1.2
Interior, Department of the	64,722	366,421	—	—	431,143	.7
Health and Human Services, Department of	577,215	1,385	1,342	—	579,942	.9
Commerce, Department of	577,205	2,272	1,075,502	96,450	1,751,429	2.7
Other	8,358	—	5,928	—	14,286	—
Total Federal Government	45,881,733	1,761,617	2,803,148	276,757	50,723,255	78.1
STATE AND UNIVERSITY FUNDS	7,976,987	429,132	639,047	439,477	9,484,643	14.6
LOCAL GOVERNMENT	26,963	—	11,117	—	38,080	—
PRIVATE GIFTS AND GRANTS	3,368,871	132,441	463,324	(1,682)	3,962,954	6.1
ENDOWMENT FUNDS	500,577	31,974	34,481	24,026	591,058	.9
SERVICES, RESERVES AND MISC.	99,657	(127,535)	210,988	—	183,110	.3
Total Current Funds Expenditures	$57,854,788	2,227,629	4,162,105	738,578	64,983,100	100.00

ECKART DISSERTATION PRIZE



N. HULBIRT

Dr. Carl H. Eckart

Dr. Paul G. Silver

Dr. Paul G. Silver received the 1982 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. Silver's thesis presented a method for estimating specific scalar seismic moments from noisy seismic data when the source mechanism is uncertain or completely unknown. He formed new hypotheses concerning rupture propagation in the lower lithosphere and volume changes within the source region of earthquakes.

All correspondence pertaining to this report should be directed to:
Technical Publications
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Scripps Institution of Oceanography
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