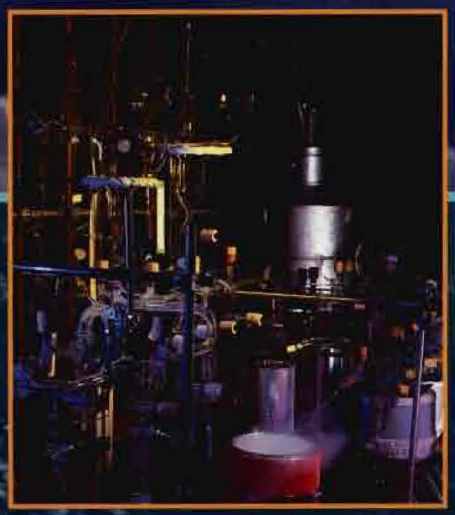
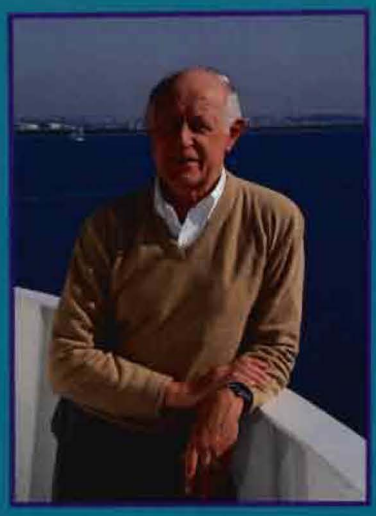
SCRIPPS INSTITUTION OF OCEANOGRAPHY

1991 ANNUAL REPORT



UNIVERSITY OF CALIFORNIA, SAN DIEGO

D E D I C A T I O N



A MAN WIDELY REGARDED as an outstanding ocean physicist, engineer, innovator, and academician, Fred Noel Spiess is a leader in American marine sciences. His quiet guidance and good advice are sought by many, and he has inspired his students and colleagues to attack diverse and significant problems.

A native Californian, Spiess is a product of the UC Berkeley Physics Department where he earned undergraduate and doctoral degrees. He began his seagoing career during four years in combat as a submarine officer in World War II. He entered ocean sciences in 1952 when Carl Eckart and Roger Revelle convinced him to join the Marine Physical Laboratory (MPL), which he subsequently directed from 1958 to 1980.

Spiess's interests are varied, including sonar system concepts, underwater sound propagation, the fine-scale structure of the seafloor, and phenomena associated with plate tectonics and seafloor spreading. In pursuit of these studies and others, he has conceived and collaborated in development of innovative devices for ocean studies, such as the research platform FLIP and the remotely operated vehicle Deep Tow.

The Navy and the National Academy of Sciences long ago recognized his ability to turn big problems into little ones by appointing him to the Naval Research Advisory Committee, the Ocean Science Board, and a host of other committees. In 1985, he was elected a member of the National Academy of Engineering, and received the Pioneers of Underwater Acoustics medal of the Acoustical Society of America.

Spiess's service to Scripps, MPL, and the University of California is exceptional. He has served twice as chairman of the Graduate Department, as acting director of Scripps, as director in 1964-1965, and as an associate director of Scripps for 15 years. From 1980 to 1988, he was the director of the UC Institute of Marine Resources, headquartered at UCSD. He has held numerous positions within the UC Academic Senate, including serving as a faculty representative on the UC Board of Regents and chair of the universitywide Academic Council and Assembly.

With his wife, Sally, he is an integral part of the Scripps community and La Jolla. Together they spearheaded the work to save and restore the institution's first permanent building, and they continue to serve as leaders of their church and other organizations.

Having led expeditions for more than 30 years, Spiess, although now an emeritus professor, continues with seagoing programs. As he said when he received the Ewing Medal from the American Geophysical Union and the U.S. Navy in 1983, "I enjoy competing with the ocean for knowledge of its secrets."

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*Current June 30, 1991

INTRODUCTION

THE PAST YEAR AT SCRIPPS has been eventful. On the positive side, our research and education programs have never been healthier. We have continued the addition of outstanding members to our faculty, with 10 joining us over the past 18 months; our extramural funding from federal sources was up significantly, taking our expenditures to an all-time high of over $72 million; and our capital construction programs, with the new Stephen Birch Aquarium-Museum and the major IGPP extension, are moving along rapidly. These recessionary times, however, have caused us concern and some pain because 25% of our funding comes from the State of California. Thus far we have survived budget cuts without grave damage to our research and education programs. One of the reasons for this is our federal grants are up significantly, 25% from the National Science Foundation alone. There is no question that our strong showing nationally attests to the excellence and the innovative research of the faculty and staff at our institution.

We have all been deeply saddened by the loss of our good friend and colleague Roger Revelle. Roger died on July 15, 1991, and his ashes were scattered at sea from Scripps's R/V *New Horizon* on July 19. Roger remained active at Scripps and UCSD, visiting his Scripps office almost daily until his death. We all miss Roger.

A number of exciting opportunities for Scripps have also emerged. An NSF Science and Technology Center designed to unravel the role of clouds in regulating global climate and climate change was awarded to Scripps professor Veerabhadran Ramanathan. Walter Munk's Heard Island experiment using underwater acoustic signals to determine global changes in the earth's temperature was an unqualified success and is discussed in the Highlight section.

Scripps's R/V *Melville* is expected back into operation around February 1992, after a $20 million overhaul, including a 10 m lengthening to 85 m. After intense competition with other major oceanographic institutions, Scripps was awarded a new research ship by the Office of Naval Research, with construction to begin in May 1992. This $40 million plus vessel will add significantly to the capabilities of our existing fleet, which pursues research worldwide. We have proposed to the U.S. Navy that our new ship be named R/V *Roger Revelle*.

It is also a pleasure to announce that a joint institute between Scripps and the National Oceanic and Atmospheric Administration has been established at Scripps. This institute will be devoted primarily to long term ocean observations, but will also include our Experimental Climate Forecast Center, and a fisheries component. It should also add impetus to our existing programs. We recently signed agreements for cooperation with oceanic research institutions in Japan and Korea. Close cooperation in research between Scripps and Pacific Rim countries could prove extremely beneficial to our goals and objectives, and I hope to expand such cooperative efforts in a substantial way.

Our financial development program is continuing. Over the past year we have created a new Scripps Institution of Oceanography Associates program. We have also committed to a major development effort to increase our endowment through a 2-for-1 foundation challenge grant of $1.2 million.

These are important times for our institution. Our research on the environment of the earth and its oceans becomes more important to the well-being of our planet with each passing year. Our goal and mission is to keep Scripps preeminent in this search for new knowledge.

Edward A. Frieman, Director
December 10, 1991

Eugene LaFond

Last summer, Roger Revelle, "the man who lead Scripps to sea" died at the age of 82, bringing to an end an extraordinary career in science and humanities. Long-time friend and colleague, Walter Munk, offers these notes and memories of Roger and Scripps and what they meant to each other. The material was assembled at a small lake in Austria, where 37 years earlier, Roger and Ellen visited with Walter and Judith.

Inset. Roger Revelle, c1936.

Background. Roger Revelle with Allen bottle, n.d. [1930s]

THE REVELLE YEARS

by Walter Munk

ROGER WAS APPOINTED Associate Director of Scripps in March 1948, acting director in March 1950, and director in July 1951. After July 1958 when Roger became director of the newly formed Institute of Technology and Engineering, at the then University of California at La Jolla (in addition to his Scripps duties) his attention increasingly turned to the founding of UCSD. During this decade 1948 to 1958, between the ages of 39 to 49 years, Roger transformed the Scripps Institution of Oceanography into a global, seagoing enterprise, helped set the stage for plate tectonics and global warming, and played a leading role in upping national support for oceanography by an order of magnitude.

Roger had been with Scripps for 17 years (including a service leave USN) before assuming a position of leadership. Early correspondence gives a good indication as to where he was headed[1]

> 27 January 1936
> Professor B. Helland-Hansen
> Geophysical Institute
> Bergen, Norway
>
> Dear Helland-Hansen
>
> ... Revelle has had what we call at the University of California his qualifying examinations for his doctor's degree and did brilliantly. One of the members of the examining committee ... had said that Revelle made the best showing of any candidate that he ever helped to examine. His thesis, which has already been written (is entitled) "Marine bottom samples collected in the Pacific Ocean by the CARNEGIE on its seventh cruise."... (Revelle) intends to go to Europe for about a year's work at different oceanographic institutions there. ... He will go to Bergen to work for awhile with you. ... I am going to ask you to take him more or less under your wing until he gets oriented ...
>
> T. Wayland Vaughan, Director SIO

And oriented he became! Roger describes Helland-Hansen as "brilliantly attractive, friendly - equally so to everybody, and so trusted and valued for his fairness and common sense that he had no rivals..." Helland-Hansen and Fridjof Nansen had completed 30 years of study of the northeast Atlantic (the most influential work in physical oceanography to date) aboard their sturdy research vessels *Michael Sars* and *Armauer Hansen*. At the time (in Roger's words)

> SIO had one "ship," a retired purse-seine fishing vessel named *Scripps*, sixty-four feet,ten inches long, ... Her single crew member was an ex-locomotive engineer who apparently believed that the best way to keep a boat in good shape was to cover it with grease like a steam engine. With this craft we were able to leave the port of San Diego for one- or two-week expeditions to various islands off the Southern California coast ...

One of Roger's proudest moments was when he obtained a small boat operator's license and became part-time captain. A few months later

> *Scripps* destroyed herself in an explosion, which also killed the cook (by this time the boat had acquired a crew of two) and seriously injured the engineer. I am still sick at heart about her loss ... The thing that I cannot quite become reconciled to is that our days as sailor boys are over. Henceforth we shall be merely unessential observers on board.

Years later, Roger observed:

> Despite this tragedy the accident was ultimately a blessing for the Scripps Institution. It enabled Sverdrup to approach E. W. Scripps' son Robert Scripps, with a request that he provide the Institution with a real seagoing vessel. This was done, and the Institution came into possession of a beautiful topsail schooner which was renamed *E. W. Scripps*.

Roger and Ellen were still in Norway when the vessel was acquired. Sverdrup had described her as the *Armauer Hansen* in the form of a yacht. "If so," Roger responded, "she is a damn fine boat, for we both fell in love with *Armauer*."

First long cruise of R/V *E. W. Scripps* into Gulf of California in February 1939. (*L to R*) Eric Moberg, Roger Revelle, seaman Andrew Boffinger, Richard Fleming (with binoculars), machinist Bob MacDonald, UCLA botanist George Hale, UCLA botanist Lee Haines, engineer Walter Robinson, Martin Johnson, UCLA ornithologist Loye H. Miller.

World War II came in the midst of these activities, and Lt (j.g.) Revelle went on active duty and (among other accomplishments) helped establish the Office of Naval Research.

> 25 September 1947
> Comdr. Roger Revelle
> Cosmos Club
> Washington, D.C.
>
> Dear Roger
>
> ... the reason why I am so anxious for you to come back soon is that at present I am practically the only one at the SIO with any appreciable experience in work at sea. But with the larger fishery program looming on the horizon, we shall have an enormous amount of work on our hands in order to commission and equip two or three vessels. ... you have expressed a great interest in that entire program and I am confident that, regardless of the capacity in which you return here, you are the logical man to take charge ... of work at sea. ...
>
> H.U.Sverdrup, Director SIO

John MacFall

Gustav Arrhenius and Roger Revelle, CAPRICORN expedition, 1952.

Sverdrup's words "regardless of the capacity in which you return" were a reference to the development of a fire ball of opposition to Roger as the next director, and to Sverdrup's preference for Roger as his successor. Ultimately this was to delay by three years the time when Roger assumed formal leadership. The opposition came from two sides. One was that a majority of Scripps faculty under the leadership of Carl Hubbs held that it was about time to have a biologist for director. The other had to do with some of Roger's administrative habits. My own conviction, then and now, is that the opposition was petty and ill informed. But I had better let Roger speak for himself. In a letter of 7 November 1947 to Dean M. P. O'Brien, he refers to

> ... my obvious and numerous weaknesses, such as a tendency to procrastinate, to take on too many obligations, not to delegate authority, and to be high-handed ...

But there is no question that Roger wanted the job. In the same letter, he writes

> Sverdrup's support for me as successor is also based upon the fact that I am practically the only person available who has had extensive experience at sea, in particular in the organization and carrying out of expeditions. He feels that Scripps must be, at least in part, re-oriented towards work on the high seas rather than the inshore and laboratory type of research which is being largely done at present.

The final outcome was a compromise proposed by Roger himself in a letter of 6 January 1948 to Sverdrup:

> I believe that a merger of the Marine Physical Laboratory with the Scripps Institution would be desirable and fruitful ... If such a merger took place, I believe Carl Eckart might be persuaded to assume the directorship of the combined organizations. I would be glad to serve as Associate Director under Dr. Eckart with the understanding that I would have, under his general direction, the responsibility and authority for administration of research and field work.

Carl Eckart was glad to accept this arrangement, and from the time Roger and Ellen returned from Washington D.C. in March 1948 Scripps carried the Revelle stamp. But the opposition continued until his final appointment as director in July 1951.

April 12 1950
President Robert G. Sproul
University of California

Dear Mr. Sproul:

We understand that the impression has been gained in some quarters that opposition is vanishing at Scripps Institution to Dr. Revelle as a candidate for Director. We assure you that whereas we have a high regard and friendship for him, we feel as strongly as before that his appointment ... would not be in the interest of the institution. His recent administrative actions confirmed our conviction ...

Dennis Fox, Carl Hubbs, G. F. McEwen, Francis Shepard, Claude ZoBell.

A note in President Sproul's files dated June 9, 1950 quotes a discussion with Shepard, who "... feels that it would be an injustice to Revelle and to the Institution if he were reappointed, since he has little or no administrative skill." But many years later, Shepard was to refer to Roger's "brilliant Directorship."

With the clarion call: the Pacific is our oyster, Roger led a timid faculty into the blue water of the deep Pacific. The CalCOFI studies (California Cooperative Oceanic Fisheries Investigations) planned by Sverdrup were getting under way. One of Roger's first tasks as associate director was assemble enough instruments and trained personnel to support the required three ships. At the same time he permanently marked this program with an environmental approach to fisheries biology. This work is still continuing and constitutes an unequalled record of the physical environment and its biological consequences in a large ocean area.

Edward Sheldon Barr

John Isaacs, Roger Revelle, and H. William Menard discuss plan for the day, MIDPAC expedition, 1950.

Fritz Goro

Clockwise from Roger (12 o'clock)* Walter Munk, Gustav Arrhenius, Willard Bascom, John Steinbeck, Josh Tracey, Jr., Unidentified and William Riedel, *(examining specimen.)

The era opened in 1950 with the MID-PACIFIC expedition into the equatorial waters and to the Marshall Islands in the Central Pacific. This was followed in 1952-1953 by an extended voyage to the South Pacific which was called the CAPRICORN expedition. Both expeditions were led personally by Roger. In his words,

> they resulted in a set of remarkable discoveries about the ocean floor and what lies beneath it, and were the first of a long series of expeditions, extending further and further from San Diego until Scripps ships literally operated in all oceans throughout the world.

Some of the expeditions have become household words in oceanographic literature: NORTHERN HOLIDAY, SHELLBACK, TRANS-PAC, NORPAC, EASTROPIC, EQUAPAC, DOWNWIND; a generation of expedition leaders rose through the ranks, among them Bill Menard, Warren Wooster, Bob Fisher, Fred Spiess, and George Shor.

Among the discoveries of MIDPAC and CAPRICORN was the demonstration by Russell Raitt that only a thin layer of sediments overlies the solid rock, and by Edwin Hamilton that the flattopped seamounts at a depth of 2,000 m had been volcanic islands less than 100 million years ago. This spoke for great mobility of the "solid" Earth. On MIDPAC Arthur Maxwell found the heat flow through the sea floor to be "normal," suggesting to him, Roger, and Sir Edward Bullard that slow convective movements were occurring in the Earth's mantle. When Roger and his associates tried to core and dredge the Tonga Trench, the instruments came up battered and bent, and empty. If there were any sediments, they were sparse and thin. The observations could best be explained if the rocky sea floor was disappearing into the Earth along the axis of the trench (this is now called subduction). On CAPRICORN Ronald Mason towed a magnetometer behind the vessel and recorded a complicated set of wiggles that no one could understand. Later Mason produced a map of the magnetic field under the sea floor showing stripes of normal and reverse magnetization.

On hindsight, the evidence was all there for proclaiming the doctrine of plate tectonics, but it was a decade before others pieced the puzzle together. In Roger's words:

> In those heady days of the 1950's one could hardly go to sea without making an important, unanticipated discovery. Our small ships didn't cost very much to operate and many SIO expeditions were led by graduate students. John Knauss obtained his Ph.D. on the basis of expeditions to study the equatorial undercurrent in the Pacific. Warren Wooster was a graduate student when he led several expeditions to study currents and water masses of the Central North Pacific.

Even as he led the exploration of the Pacific, Roger looked beyond the oceans. It had been suggested, beginning with Svante Arrhenius in 1898, that the activity of mankind must be leading to an increase in CO_2. Because the oceans contain about sixty times as much CO_2 as the atmosphere, there was a general belief that CO_2 from fossil fuels would be partitioned in this ratio. Computations by Revelle and Suess in 1956 showed that about half the fossil CO_2 would remain in the air. This led to the continuous CO_2 measurements started by Keeling in 1957, perhaps the most widely known of Scripps's activities.

SIO Archives

Roger Revelle, c1958.

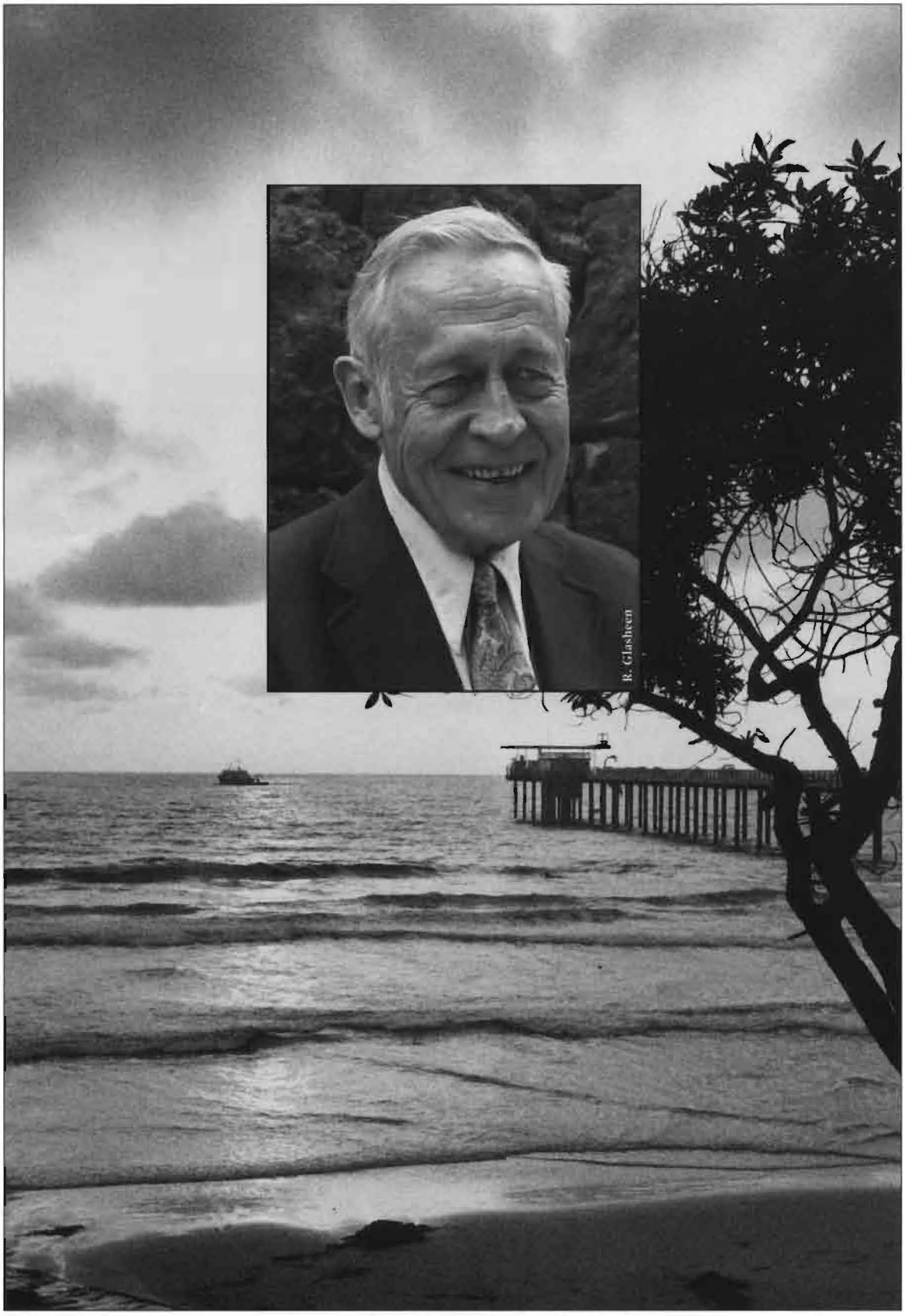
Again in 1957 Roger was among a group that promoted an attempt to drill through the ocean floor into the Earth's mantle. This MOHOLE project was ill-fated, but a forerunner to a subsequent program of deep-sea drilling at the Scripps Institution.

But by then Roger was deeply involved in the formation of what is now UCSD. Oceanographer Henry Charnock quotes Roger that an oceanographic institution that was not linked to a university would only survive one generation. So there was no conflict between his continuing activity as SIO Director. There were other conflicts; with Regent Edwin Pauley who advocated Balboa Park for a site of the new university; with UCLA who wanted us to start teaching only freshman and sophomore courses (what does a bunch of sailors know about higher education?); and with the Salk Institute concerning the appropriation of San Diego Pueblo Land. Roger won most of them, but as it happened to Pyrrus of Epirus, he won one too many. In 1961, when it came time to appoint the first chancellor, Roger was passed over. It was his second great disappointment; the first one had happened in 1947 when he did not become Scripps's Director upon leaving the Navy.

In 1975 Roger returned from exile at Harvard University, where he had held the Richard Saltonstall Professor of Population Study to UCSD where he became Professor of Science and Public Policy. What an exile it had been, but this is another story. The circle was completed when in September 1990 he moved to an office next to the Director of the Scripps Institution. Throughout his career, when questioned about his profession, Roger would reply "I am an oceanographer." But this was hardly restrictive; on more than one occasion I have heard him define the profession of oceanography: whatever anyone at Scripps does.

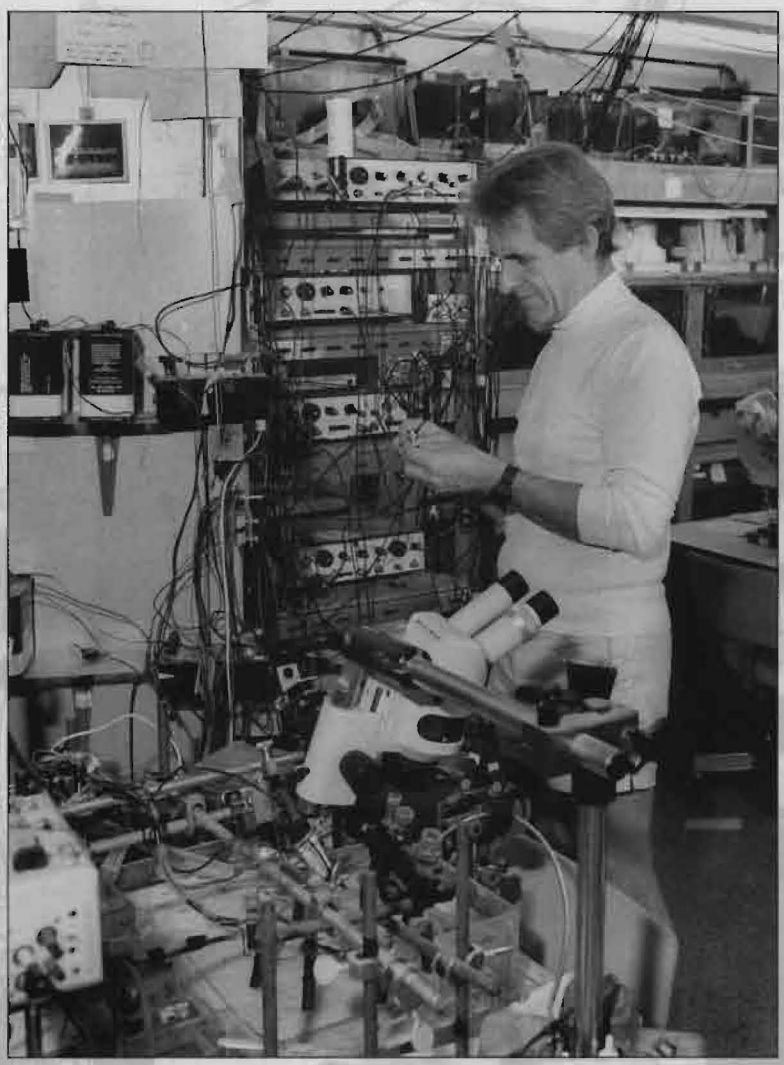
Walter Munk
Alt-Aussee, Austria, August 1991.

[1] These and other quotes are from Roger Revelle papers in the SIO Archives. I am greatly indebted to Deborah Day for assembling much of the material used here.

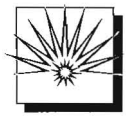


Inset. Roger Revelle, 1976.

Background. Farewell to Revelle - Roger's last expedition, July 19, 1991.



Dr. Walter F. Heiligenberg prepares equipment before an electrophysiological experiment.



Neuronal Information Processing in Electric Fish

by Walter F. Heiligenberg

THE MYSTERIES OF THE BRAIN and nervous system intrigue biologists and computer scientists. We are working at the lower end of the evolutionary scale to find an upward leading trail. Our study of electrosensation in fish has resulted in a variety of model systems for the exploration of neuronal phenomena, ranging from the behavioral to the cellular level. The close integration of behavioral, anatomical, and physiological approaches has been instrumental in our research, and studies at a higher level of integration have identified the biological importance of phenomena to be explored at the next lower level.

We study electrosensory systems in fish because the more highly evolved systems, such as vision and audition in birds and mammals, are more cluttered and difficult to study. Yet, the basic neuronal designs found in electrosensation, being old and conservative in the evolutionary sense, are similar to those in higher and more advanced systems. Some behavioral responses of electric fish are so robust that they remain intact in physiological preparations, thus allowing us to study behavioral and cellular aspects simultaneously.

Some species of tropical fish generate weak electric fields by regularly discharging an electric organ located in their tail. The fish's own electric organ discharges (EODs), as well as those of neighbors, are detected by electroreceptors on the fish's body surface. Electric fish modulate the timing of their EODs during social communication, such as courtship and aggression. Also, analysis of distortions of the fish's own EOD field, caused by the appearance of objects that differ electrically from water, allows them to interpret the nature and motion of these objects. This mechanism of object exploration is a form of 'seeing' with the body surface—called 'electrolocation'. Electric communication with neighbors requires mainly a temporal and spectral analysis of electric signals, but electrolocation also calls for a spatial assessment of electric fields.

Electrosensory information from receptors is relayed by primary afferent nerves to neuronal assemblies in the brain. These assemblies form 'maps' of the electrosensory body surface. The arrangement of neurons within such maps reflects the topographic order between the receptors that feed inputs to these neurons. The interactions between these neurons provide a network of parallel processors that detect and select specific spatial and temporal patterns of receptor stimulation. The neuronal maps closest to the receptor input are found in the 'electrosensory lateral line lobe' (ELL) of the hindbrain. Still higher-order electrosensory maps are found in the midbrain. Their topographic convergence with a visual map in the optic tectum provides a multimodal representation of the world outside.

Sensory information is often processed by several maps, and while one map may excel in its resolution of temporal information, another map, receiving the same raw information, may be superior in its resolution of spatial details. We find that an enhancement in temporal resolution requires sacrifices in spatial resolution, and vice versa. Therefore, the nervous system has chosen different 'hardwares' to achieve high temporal and spatial resolution of stimulus patterns in parallel.

With ascending order, neuronal maps

become more and more complex and adapted to the control of specific behaviors. Whereas neurons within maps of lower order still have rather general response properties and appear to participate in the control of very different forms of behaviors, neurons in higher-order maps are tuned more finely to specific behaviors. These higher-order neurons display stimulus specificities and sensitivities comparable to those observed at the behavioral level. Whereas maps for sensory processing retain the topography of the body surface, maps closer to the control of specific behaviors abandon this spatial order. These maps, organized in accordance to motor coordinates, are referred to as 'motor maps'.

Sensory pathways meet upon nuclei in the brain that are dedicated to the control of specific behaviors. Different forms of behavior may require use of overlapping pools of premotor neurons—neurons controlling muscles and their derivatives, such as electric organs. As a result, different brain nuclei may have access to the same set of premotor neurons and regulate their operation in different ways. In the case of the pacemaker nucleus, which controls the electric organ, different 'prepacemaker' nuclei can induce different forms of modulations in the firing of this oscillator and thus cause corresponding EOD patterns; and different modulations are induced by different transmitters and transmitter-receptor subtypes. The same output structure, therefore, can generate different forms of behavior.

We find that neural networks at the sensory and the motor ends of the nervous system are shared by different behavioral systems. Sensory pathways 'fan in' upon the brain nuclei dedicated to the execution of specific behaviors, and motor pathways 'fan out' from these nuclei to recruit shared pools of output neurons.

As our studies continue, we hope to clarify the operation of neural networks in general and to come closer to understanding our own brains in particular.

Eigenmannia **in tank during an experiment. The electric organ discharge is shown on the oscilloscope in the background (*lower right*).**

Grace Kennedy at the electron microscope searches for stained neurons in a section of a fish brain.

Suggested Reading:

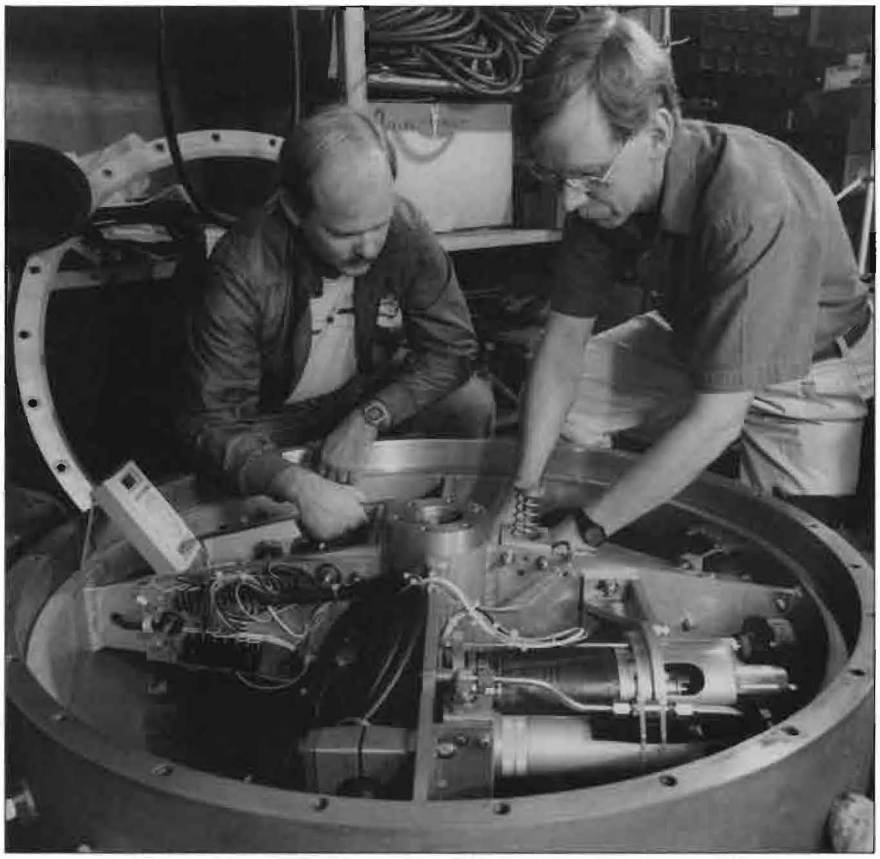
Heiligenberg, W. The neural basis of behavior: a neuroethological view. *Annual Review of Neuroscience*, v.14, 1991. pp.247-267.

Heiligenberg, W. The jamming avoidance response (JAR) of the electric fish, *Eigenmannia*: computational rules and their neuronal implementation. In: *Seminars in Neuroscience*, v.3, no.1, edited by J. Altman and D. L. Sparks. London, Saunders, 1991. pp.3-18.

Shumway, C. Multiple electrosensory maps in the medulla of weakly electric gymnotiform fish. I: Physiological differences. *Journal of Neuroscience*, v.9, 1989. pp.4388-4399.

Acoustic Monitoring of Global Ocean Temperature?

by Andrew M. G. Forbes



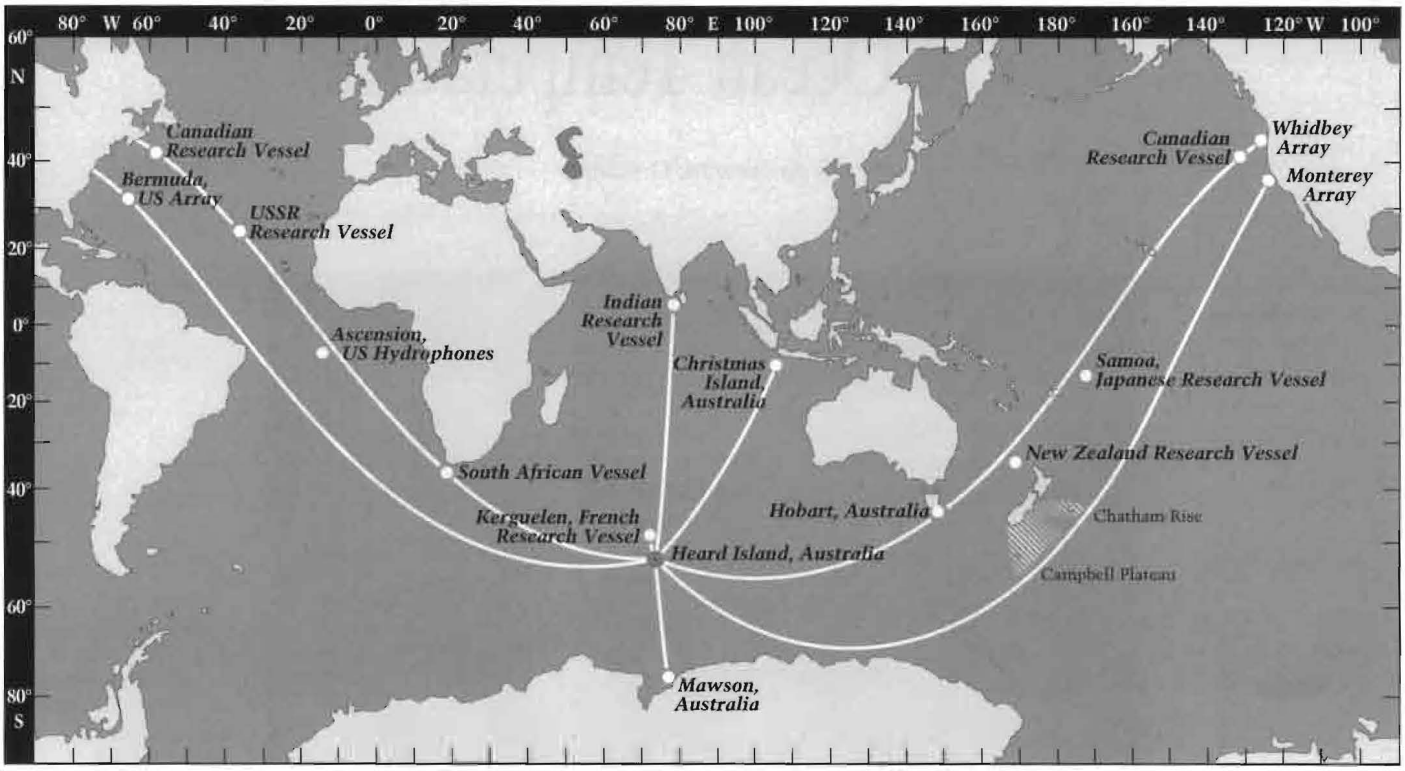
Andrew M. G. Forbes, *right*, and Douglas Peckham examine an acoustic source similar to the one used in the Heard Island Experiment.

RECENTLY A BIG QUESTION mark followed a similar title, which appeared on a paper published by Dr. Walter H. Munk and Andrew M. G. Forbes in the *Journal of Physical Oceanography*. In it, they predicted that it should be possible to acoustically measure very long path averages of ocean temperature accurately enough to detect greenhouse warming in the ocean.

Now the big question mark has faded dramatically, following a unique experiment carried out at remote Heard Island in the near-freezing waters of the Southern Ocean. The Heard Island Feasibility Test (HIFT) was designed to test an acoustic "thermometer" over ranges extending to 15,000 km. The technique relies on one fact; that at a given depth in the ocean, temperature is the main influence on sound speed, so changes in acoustic travel times between source and receiver can be used to measure temperature variability.

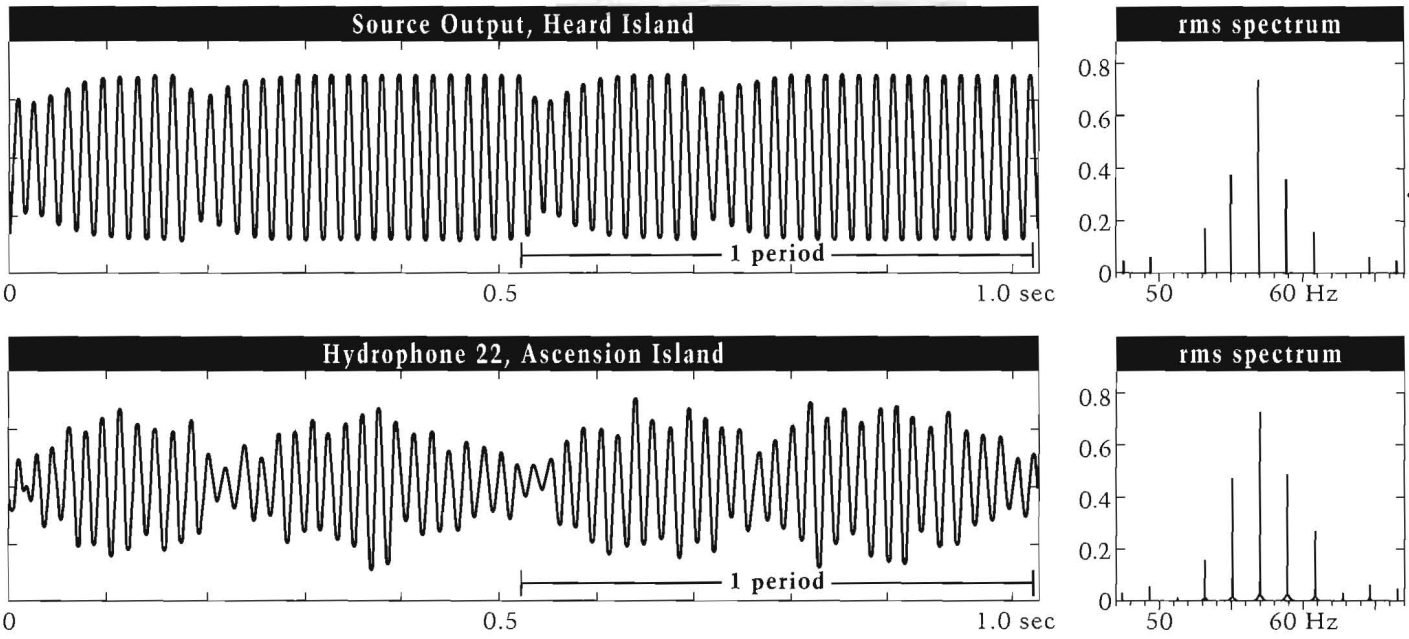
Along a 15,000 km path, the temperature of the ocean is not uniform. Parts of the path may go through polar, temperate, and tropical waters, but travel time measured for the whole path yields a path-averaged temperature. We take advantage of the fact that the ocean naturally integrates sound speed, and therefore temperature, along such paths.

Temperature changes take place in the ocean on many different time and space scales, ranging from minutes and meters (internal waves), to days and hundreds of kilometers (mesoscale eddies) and to months and



Map shows sending station at Heard Island and the 14 receiving stations.

Below, the signal is shown as sent from Heard Island (top) and as received at a distance of 9,200 km at Ascension Island (bottom).



megameters (ocean gyres). The acoustic method tested in HIFT can be used to examine these changes in detail at many places along the path, or to average out these changes over thousands of kilometers and over many years, and thus determine large scale, long-term trends in ocean temperature.

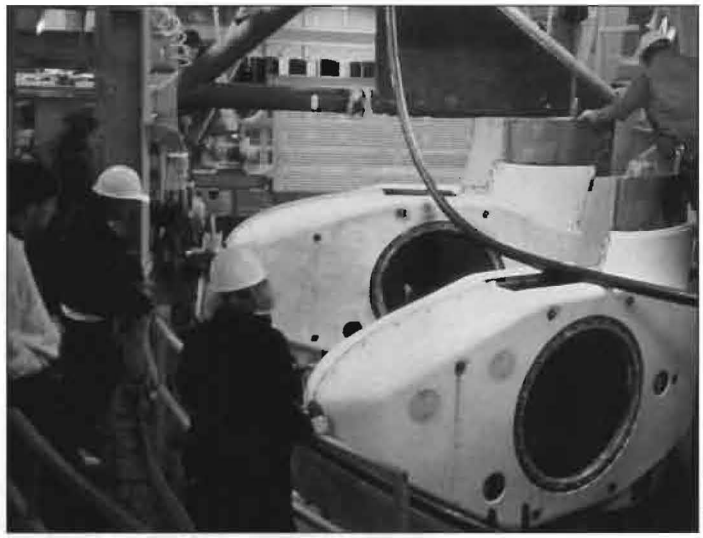
In January 1991 R/V *Cory Chouest* carried a team of oceanographers from Scripps, the University of Washington, and the University of Michigan to a site 70 km offshore of Heard Island. Signals from an acoustic source at this location were broadcast into the sound channel (found at the depth where sound speed is a minimum in the ocean) for one hour in every three throughout five days. Despite intermittent bad weather at Heard Island and at a number of receivers, the signals were received at 14 of the 16 stations. The quality of the receptions was excellent in most places. Travel times have now been calculated with a precision of 100 milliseconds even on the longest paths (Heard to Bermuda and Heard to Whidbey Island, Washington) and with further signal processing, 10 ms accuracy will probably be achieved.

The types of coded signals broadcast during HIFT have been used by Drs. Peter F. Worcester and Munk for many years in their acoustic tomography experiments. For HIFT a very low carrier frequency (57 Hz) was used to minimize attenuation. It had two additional advantages; the low frequency was below the range of hearing of most marine mammals and the code allowed a much lower intensity (20 dB less) to be used (since computer processing of the coded receptions realizes a 20 dB gain).

Several months before HIFT started, there were concerns raised in some parts of the community about the possible effects of several days of low frequency acoustic transmissions on the marine mammal population of the Heard Island area. After careful assessment of possible impacts, Marine Mammal Permits were granted by both the United States and Australian governments and a major mammal observation program was mounted in parallel with the acoustics experiment. A second ship accompanied R/V *Cory Chouest* to Heard Island carrying a team of marine mammal observers and bio-acousticians from NOAA's National Marine Fisheries Service and Australia's Antarctic Division. After a thorough pretransmission survey of the mammal population (recording their density, diversity, and behavior) the team was ready to observe any possible effects that the intermittent transmissions might have on the mammals. Several weeks and hundreds of observations later, the team concluded that the marine mammals in the area exhibited their normal range of behavior in the presence of ships—some showed curiosity, some ignored the activity, and others moved away. The observers could not distinguish any abnormal response that could be attributed to the presence of the acoustic signals alone.

Work has already begun on the long-term Heard Island Program. Our goals are now better defined and the techniques of studying global acoustics are developing rapidly. A Scientific Committee on Ocean Research working group has been set up that has already attracted the enthusiastic involvement of nine nations, many of whom participated in HIFT by providing ships, personnel, and in some cases, receiver arrays. Processing of the received data is well under way and we can now recognize distinct differences in the character of signals which passed through eddy-rich regions from those which passed through less turbulent waters. We originally expected only the lowest one or two acoustic modes to survive such great distances, but we have separated (but not yet identified) higher modes that were not confined to the axis of the sound channel.

Acoustic transmitters aboard R/V *Cory Chouest* during the Heard Island Experiment.



Robert Spindel

Specifications for a long-term, reliable source are now much clearer and a development program will soon be under way.

Heard Island itself is no longer a candidate for a permanent acoustic source—the shallow sound channel there is too seasonally variable and its remoteness is forbidding. But much was learned by using Heard as a test bed and the future program will retain the name as a source of inspiration if not sound.

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Decades of Data

by John A. McGowan
and Dean H. Roemmich

Dr. John A. McGowan explains part of the 75-year-old west coast shore station data collection program.

ONE OF THE MOST SIGNIFICANT lessons learned by oceanographers in the past decades is that global trends cannot be detected from scattered stations with years or even decades of data. The climate-ocean system is simply too rich in spatial variety and temporal fluctuation to yield to such naive approaches. A very long-time series of highest quality data is required from many locations to facilitate this type of study.

With great foresight the Scripps west coast shore station program was started in 1916. This program, now 75 years old and managed by the Marine Life Research Group, is a compilation of temperature and salinity records from sites along the California, Oregon, and Washington coastline. In 1916 daily samples of sea-surface temperatures and salinities were recorded off the Scripps pier. This was followed by similar programs at Pacific Grove (1919), Balboa (1925), and the Farallon Islands (1925). Over the years more stations were added to the program as various agencies contributed facilities and generous volunteers came forth. There are now fourteen locations (the youngest being Trinidad Beach in Northern California, 1975) stretching from La Jolla to Neah Bay on the Straits of Juan de Fuca, Washington.

Coastal data serve as a reasonably good and inexpensive proxy for offshore changes. Not surprisingly both temperature and salinity show pronounced seasonal cycles, but also, not surprisingly, both show substantial interannual departures from the long-term averages. The mean seasonal

cycles and the departures from these long-term means are of similar amplitude.

Summer 1990 surface temperatures were unusually warm at both ends of the chain of stations. At La Jolla, the July to August temperatures were the third warmest on record, exceeded only by the summers of 1931 and 1984. While April and May were also warm at La Jolla, they were not clearly so at Neah Bay. Piecing together information like this is important, for it gives us much insight into the scale and magnitude of coastal oceanographic events. The cross-correlation of anomalies at various scales of sample separation in space can tell us much about the spatial scales of coastal events. Further, the timing of such events can tell us whether they are synchronous or proceed as a wave-like disturbance up (or down) the coast.

Often anomalous events in temperature and salinity do not happen independently of one another and, in turn, they are frequently related to sea level as measured at tide gauges nearby. At low frequencies all three variables—temperature, salinity, and sea level—are well correlated with measurements offshore. This is a further indication that the variations are caused by broad oceanographic phenomena rather than local changes. These episodes, in turn, show a good relationship to climatic variations. For example both the 1958-1959 and the 1983-1984 strong El Niños were clearly recorded at all 14 stations up and down the coast. Comparable warm sea-surface temperature events occurred in 1926, 1931, and 1941. In 1982 early evidence from these stations heralded the onset of an El Niño, and thus a special series of monthly California Cooperative Oceanic Fisheries Investigations (CalCOFI) cruises were scheduled to measure the water column structure offshore and at depths. This study remains one of the most informative on the consequences of an El Niño to nutrient, chlorophyll, and zooplankton patterns in the California Current.

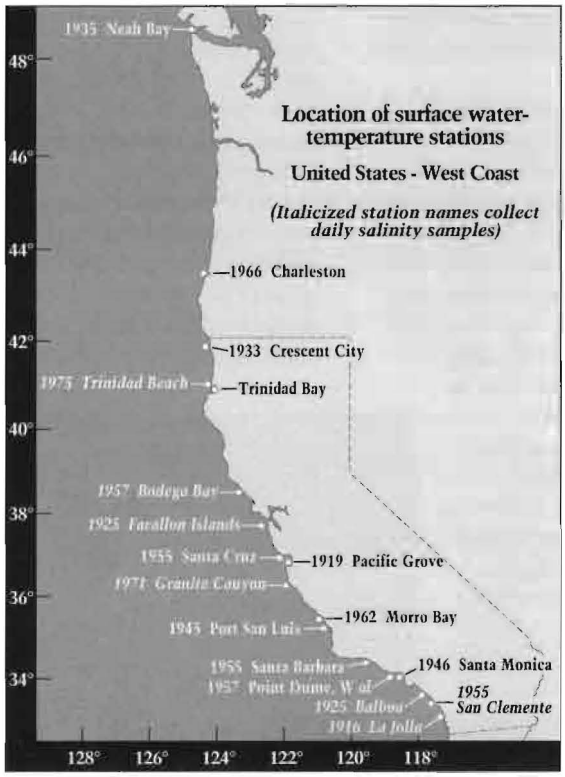
In 1983 additional measurements were begun at Scripps Pier in La Jolla. Chlorophyll and phaeophytin are now measured twice a week along with temperature and salinity. In 1986 the plant nutrients nitrate, nitrite, phosphate, and silicate were added to the suite of regular measurements. The chlorophyll and nutrient data are highly variable with strong episodic outbursts and long periods of relatively low level variations. The largest anomalies are low frequency. A major focus of the nutrient and chlorophyll sampling is to examine relationships between physical and chemical parameters. Conventional wisdom leads one to expect the episodic appearance of upwelled, subsurface water (low temperature, high salinity, and high nutrients) should precede high chlorophyll values. The existing nine years of data are not a clear confirmation of this expectation. There may be other mechanisms at work. These new observations should prove to be particularly interesting should a cold event as extreme as the 1933 or 1975 La Jolla cool sea-surface temperature anomalies occur in the future.

SIO Archives

Winfred E. Allen in the 1920s collecting phytoplankton samples off the Scripps Pier as part of his daily 20-year time series.

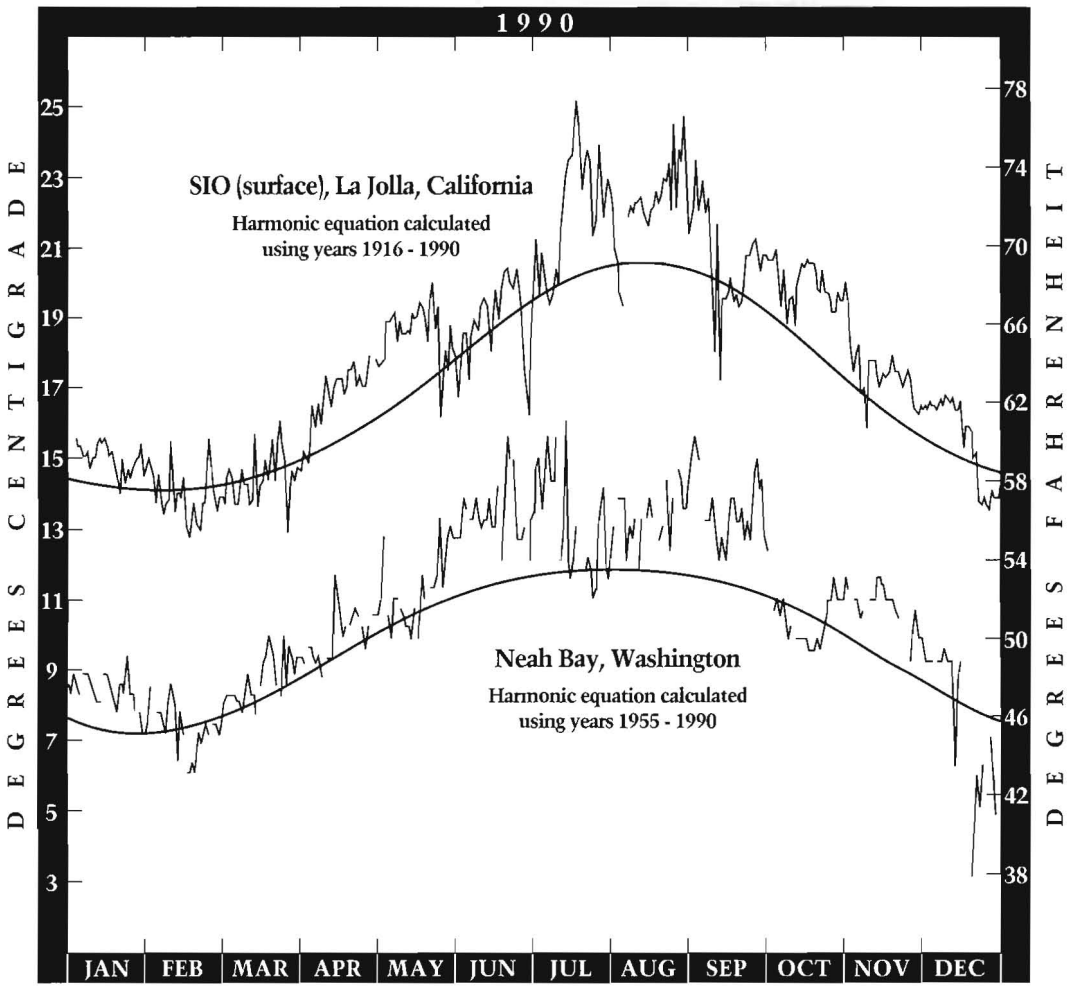
Although temperature and salinity variations seem to be closely related to offshore changes in surface values, chlorophyll and nutrients are not. Chlorophyll values off Scripps Pier are systematically higher than in the offshore surface waters. This has great implications to the intertidal and littoral fauna. Most of them are filter feeders that depend on phytoplankton, and chlorophyll is a good index of phytoplankton abundance. As yet we have no firm ideas as to what may regulate the variations in abundance of the very near shore phytoplankton biomass. Clearly more sampling sites are needed so that the spatial dimensions of the variations can be determined. Is the high level a general phenomenon all along our coast? Are the outbursts local or widespread? Last year three stations were established in Chile using procedures and methods similar to ours. The results, so far, look familiar!

West coast daily temperatures are



Right. The locations of the fourteen stations from Neah Bay, Washington, to Scripps Pier.

Below. A graph of daily temperature data for 1990 compares temperature variations from La Jolla, California, to Neah Bay, Washington.



measured at all the United States west coast shore stations but salinities at only six. The temperature data are read at each locale and mailed to Scripps. Salinities are obtained from seawater samples collected in special salinity bottles and forwarded to Scripps at the end of each month for analysis. Seawater densities are also calculated for each date that has both a temperature and salinity measurement.

The data are made available annually in a Scripps data report where daily values are tabulated along with monthly and yearly means. Ranges and standard deviations and monthly and yearly anomalies from long term means are also shown. A recent addition to the report are graphs of the current year's departures from the long term seasonal curves.

The Scripps Pier meteorological data archive is another data set collected in a joint venture between the National Weather Service (which provided the initial instrumentation), and Scripps (which installed and maintains the hardware). At Scripps, the Shipboard Computer Group (SCG) archives the data. Most of these data values that are archived are five minute readings of five second averages. The sensors, located at the end of Scripps Pier, include wind speed and direction, air temperature, barometer, surface water temperature, bottom water temperature, and a tide gauge. Wave height and period data are also archived and are provided by the Ocean Engineering Research Group.

Time series such as these provide the base-line data for determination of climate-scale temperature change in the coastal oceans. There are few such extensive time-series anywhere in the world's oceans. This one, as it gets older, gets only better.

Top. **Patricia Walker measures the water color from the end of Scripps Pier.**

Middle. **She prepares to collect a sample of the seawater from beneath the pier.**

Bottom. **The thermometer descends into the water.**

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Arthur, R. S. Oscillations in sea temperature at Scripps and Oceanside piers. *Deep-Sea Research*, v.2, 1954. pp.107-121.

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Scripps Undergraduate Fellowship Program

by Arthur J. Spivack
and Timothy D. Herbert

Dr. David T. Sandwell discusses the satellite data from Venus with SURF program student Miguel Ruiz.

HOW DO OCEANOGRAPHERS encourage bright undergraduates to enter Ph.D. programs in the earth and marine sciences? The students with strong basic science and math backgrounds are the ones we want. Yet how can they commit themselves to a field of which they have only a vague notion? How do we get them excited about the types of research conducted at Scripps? The consensus of an informal group of faculty members meeting in the spring of 1989 was that a summer fellowship program for upper division undergraduates could be an effective means of addressing these problems and should exist at Scripps. The idea was suggested to the Scripps Director's Office and the Office of Graduate Studies and Research (OGSR). Both were enthusiastic. Thus the Scripps Undergraduate Research Fellowship (SURF) program was born.

From its conception we decided that the program would emphasize a one-on-one research experience and that the participants would work directly with a Scripps academic. We hoped to give students the chance to experience the challenges and excitement associated with scientific innovation, and to give them first-hand knowledge of graduate study without the constraints of the classroom. Hence, a major challenge was to match students with projects that they found exciting and for which they had the proper background to contribute.

That first summer 14 students from colleges and universities throughout the country participated in the 8-week SURF program. Recruiting was

informal, relying on faculty contacts with other institutions and word of mouth. Students were provided with round-trip transportation to Scripps, housing in campus dormitories, and a stipend of $2,000 from the Scripps Director's Office and the OGSR. Scripps was in charge of the academic program and OGSR administered program logistics.

The experience of the students and faculty that summer was sufficiently positive that Scripps in conjunction with OGSR decided to expand the program with specific emphasis on involving under-represented minorities. A proposal was submitted to the National Science Foundation with the Scripps Department Chairman and the UC San Diego Dean of Graduate Studies as the principal investigators. The NSF granted funds for 30 SURF fellows per year for five years. This allowed the expansion of both the program and the recruiting effort. During the summer of 1990, 35 students (25 under-represented minorities) participated. In 1991 the program further increased to 43 fellows of whom 30 were of minority background.

The fellows' primary responsibility is research. This includes submitting, during the last week of the program, a written abstract describing their work and delivering a 15 minute oral presentation to faculty representatives in the students' discipline. Fellows who elect to receive course credit are also required to complete a comprehensive term paper on their research work. In addition, there is a weekly seminar presented by a faculty member or researcher covering the range of research areas represented at Scripps. These seminars are intended to give SURF participants an introduction to current research problems.

SURF fellows have been involved in a broad range of investigations working in all of the research divisions at Scripps. During the summer of 1991 a number of SURF projects covered various aspects of climate change, including the greenhouse effect, the reflectivity of the Amazon rain forest, the relation of ocean salinity to global warming, and El Niño modeling. Ancient climate changes were examined using sediment cores, gasses trapped in polar ice, and dating volcanic rocks to determine how long ancient eruptions lasted.

Another large and diverse group of projects involved the effects of various environmental conditions on bacteria, enzymes, and metabolic rates. Several natural products chemistry projects involved isolating organic compounds from sponges and the synthesis of plant growth hormones. Projects involved with the development and testing of new technologies were concerned with electric field measurements of ocean currents, satellite based lasers for studying stratospheric chemistry, the development of a plow for submarine cable laying, and satellite global ranging systems.

Thus far program participants indeed have been interested in graduate studies, and many have continued their studies beyond their undergraduate program. In 1992 we plan to expand the program to include fifty students in their last two years of college.

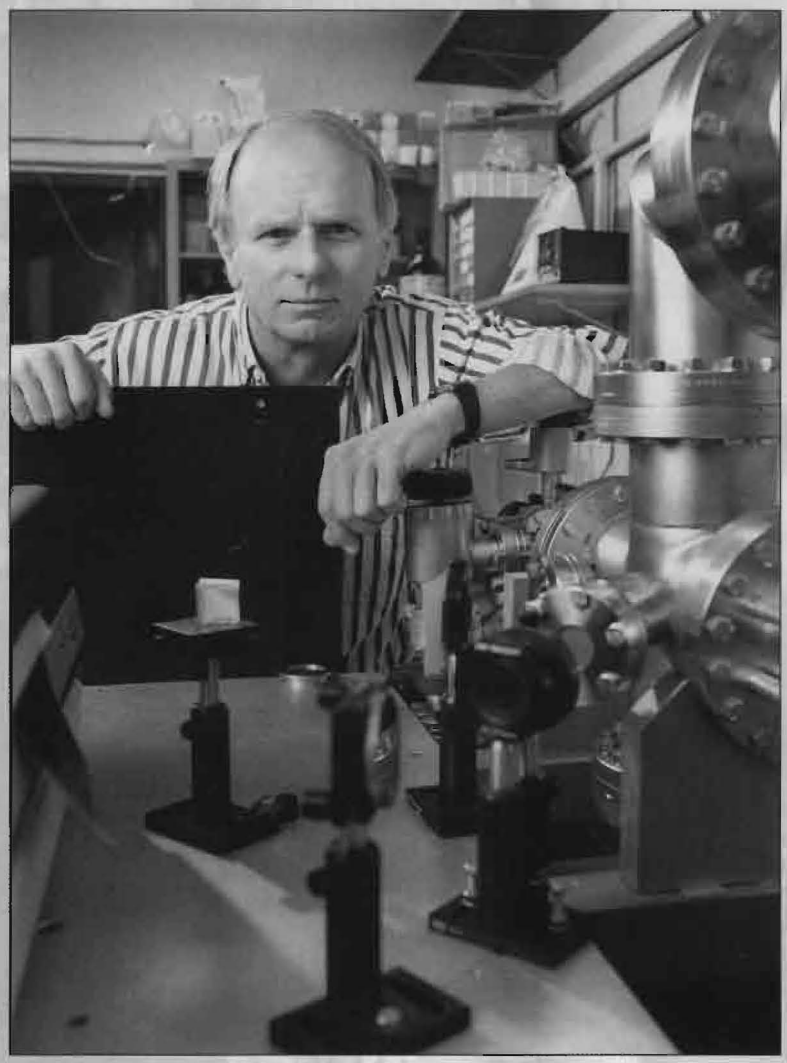
Top. **Students in the SURF program explore their research interests. Dr. David P. Rogers examines data with Ursula Hamler.**

Above. **Valerie Otero gathers retroreflectors to evaluate the weather effects on groundbased glass reflectors.**

Right. **Vincent Encomio studies sea urchin spines in a biomechanical study.**

Left. **Michael Furlough works on electronic circuits for an oceanography project.**

For additional information please write to:
University of California, San Diego
SURF, Office of Graduate Studies and Research 0003
9500 Gilman Drive
La Jolla, California 92093-0003



Dr. Jeffrey L. Bada and his laser mass spectrometer.

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 Commerce, National Aeronautics and Space Administration, 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.

Marine Research Division

SCIENTISTS IN THE Marine Research Division (MRD) conduct a variety of ocean related studies. Projects featured in this report include investigations into ocean circulation, biomedical potential of organic chemicals, marine optics, and marine engineering.

Drs. Mizuki Tsuchiya and Lynne D. Talley and a colleague completed an Atlantic Ocean circulation study based on new hydrographic data collected along a quasi-meridional section extending from Iceland southward to 3°S, 25°W. The data revealed several features including possible recirculation of the lightest Subpolar Mode Water into the tropics; an abrupt southern boundary of the Labrador Sea Water at the Azores-Biscay Rise; and a sharp demarcation in the central Iceland Basin between the newest Iceland-Scotland Overflow Water and older bottom water, which contains a significant amount of southern water. They also found evidence that Northeast Atlantic Deep Water is a mixture of the Mediterranean Outflow Water and the Northwest Atlantic Bottom Water with little input from the Iceland-Scotland Overflow Water; a core of the high-oxygen, low-nutrient Lower North Atlantic Deep Water pressed against the southern flank of the Mid-Atlantic Ridge just south of the equator; and a deep westward boundary undercurrent on the southern slope of the Rockall Plateau.

Drs. Peter M. Williams and James E. Bauer and a colleague continue to study the cycling of organic matter in the open-ocean water column. Carbon isotopic signatures (^{14}C, ^{13}C) of dissolved, suspended, and sinking particulate, and sedimentary organic carbon provide insights into the origin and lifetimes of these actively exchanging carbon pools. For example a deep marine source of suspended particulate organic carbon has been identified in both the Atlantic and Pacific oceans by using perturbations of the bomb-^{14}C signal;and high temperature oxidation techniques have revealed an additional fraction of dissolved organic carbon in the deep sea (radiocarbon age 4,000-6,000 b.p.), is similar to that previously measured in the dissolved organic carbon fraction oxidized by ultraviolet radiation. These old ^{14}C ages were also found in humic substances isolated from deep-sea waters collected at the same above sites.

Dr. Joris M. T. M. Gieskes and graduate student Andrew J. Magenheim participated in the French Operation DIANAUT. During the cruise wireline re-entry attempts were made in several Deep Sea Drilling Project boreholes in the North Atlantic Ocean. Borehole waters were obtained from hole 395A near the Mid-Atlantic Ridge and hole 534A off Florida. In the ridge hole it was shown that bottom waters fill the entire hole and that little or no reaction has occurred between the wallrocks and borehole fluids at the low prevailing temperatures. However, the hole off Florida showed significant changes in the chemical composition of the borehole fluids. It was demonstrated that upward flow occurs in this hole as the result of occasional inputs of sedimentary fluids along an aquifer at about 700 m below the sea floor.

Also in Dr. Gieskes's laboratory, graduate student Chen-Feng You studied iodide, bromide, and boron in both hydrothermal fluids and pore waters gathered from sediments in accretionary complexes. The data clarified the effects of alteration reactions occurring in the

sediments on fluids expelled from accretionary prisms as well as via hydrothermal vents in sediment covered hydrothermal systems.

In the Ocean Engineering Group (OEG), David Castel and Dr. Richard J. Seymour used data from the group's wave network to study sediment transport at Santa Cruz Harbor, infragravity surge in Monterey Bay, and the effectiveness of a new breakwater system at Fisherman's Wharf in San Francisco Bay.

Also in the OEG, Dr. David B. King studied a series of precise laboratory measurements of bedload transport of sediment under oscillatory flows. His work showed that models for this transport that involve only the fluid velocity are inadequate and that the rate of change of velocity is a major factor. He made the first observations of the effects of bed slope on transport rate and verified Bagnold's theoretical model for slope dependency.

OEG researcher Dr. Forrest E. Sloan completed his study of the effects of seawater exposure on graphite-epoxy reinforced plastic structures. He showed that there is a degradation to the fiber-matric bond under combined immersion and loading that can be damaging to flexural strength, but which, paradoxically, can increase resistance to tensile fatigue and fracture. He further examined electrochemical degradation in the presence of stray electrical currents. Careful laboratory analysis showed the formation of transient and highly reactive chemical species that were responsible for degradation of either the graphite reinforcement or the epoxy matrix.

Scientists in the Polar Research Program, headed by Dr. Osmund Holm-Hansen, participated in two major research efforts in Antarctic waters. In conjunction with another program, the group conducted studies north of the Antarctic Peninsula, which is one of the most productive areas for commercial harvesting of krill. Phytoplankton biomass and production in this area was relatively high and sustained over a three-month period. The richest areas were associated with frontal zones between different water masses, and were generally close to the meandering continental shelf break. Nutritional experiments demonstrated that neither biomass nor rate of productivity in these waters were limited by low Fe concentrations, in contrast to more northerly pelagic waters where data indicated that potential phytoplankton biomass may be limited by low Fe concentrations.

The other major Antarctic field program focused on the effect of solar ultraviolet radiation (UVR) on phytoplankton, especially in regard to the UV-B region (280-320 nm), which is the portion of the spectrum that is enhanced when stratospheric ozone concentrations are low as occurs in the 'ozone hole' over Antarctica. Photosynthetic rates of Antarctic phytoplankton in surface waters (0 to 5 m) may be doubled by screening off solar UVR, but rates were not affected below 15 m. Studies were also conducted in tropical waters to assess the adaptational state of phytoplankton that normally are exposed to high UVR flux. No significant effect of direct solar UVR on phytoplankton could be detected in equatorial waters.

Scientists in Dr. William H. Fenical's laboratory focus on two areas of marine bioorganic chemistry. Through collaborative projects with researchers at other universities, the functional effects of organic compounds produced by marine plants and animals are being explored. Dr. Antonio M. Montanari discovered that the bryozoan *Amathia convoluta* produces a series of unique metabolites that function in nature to deter fish predation.

Dr. Fenical's group also focuses on developing the biomedical potential of marine organisms. They are exploring and developing marine natural products as new molecular probes and as new pharmaceuticals. In another collaborative effort, new anti-inflammatory agents with novel properties have been developed. A recent finding is the 'fuscoside' class of anti-inflammatory agents isolated from extracts of the Caribbean octocoral *Eunicea fusca*. These compounds are impressive in their potencies and have unique biochemical properties that suggest they may be lead compounds in the development of new drugs for arthritis and asthma. Over the past several years, a new program involving marine microbiology has become a major component of the group's research. Working with the National Cancer Institute and a pharmaceutical company, novel strains of marine bacteria are being isolated, cultured, and tested for their antibiotic, antitumor, and antiviral properties. New agents are being discovered from marine bacteria and fungi, indicating that the virtually unexplored marine environment may be a significant new biomedical resource.

Dr. D. John Faulkner and colleagues are investigating the biomedical potential and ecological function of organic chemicals that can be extracted from marine invertebrates such as sponges, tunicates, and opisthobranch mollusks. This research involves extensive collaboration with academic pharmacologists and pharmaceutical companies that provide much of the advanced screening and commercial evaluation of the chemicals discovered by Scripps scientists. These collaborations have resulted in the discovery of new anti-inflammatory agents and a compound that inhibits HIV-1 protease. Other materials are being patented by our industrial collaborators. After ten years of research, a pharmaceutical company has abandoned efforts to evaluate manoalide—a metabolite from a western Pacific sponge—as a treatment for psoriasis. Manoalide had reached phase two clinical trials. While this is a disappointment, it does not detract from the fact that manoalide is now marketed as an inhibitor of phospholipase A^2, an activity that was discovered as a result of our joint studies with scientists at UC Santa Barbara. New compounds from this program are currently being evaluated in preclinical experiments.

Marine natural products are also being evaluated for their ability to deter predators and fouling organisms. Sessile invertebrates cannot survive if they are eaten by fish or are heavily fouled by competing organisms. There is good evidence that chemicals produced by sessile invertebrates can deter both predators and fouling organisms and experiments to test this hy-

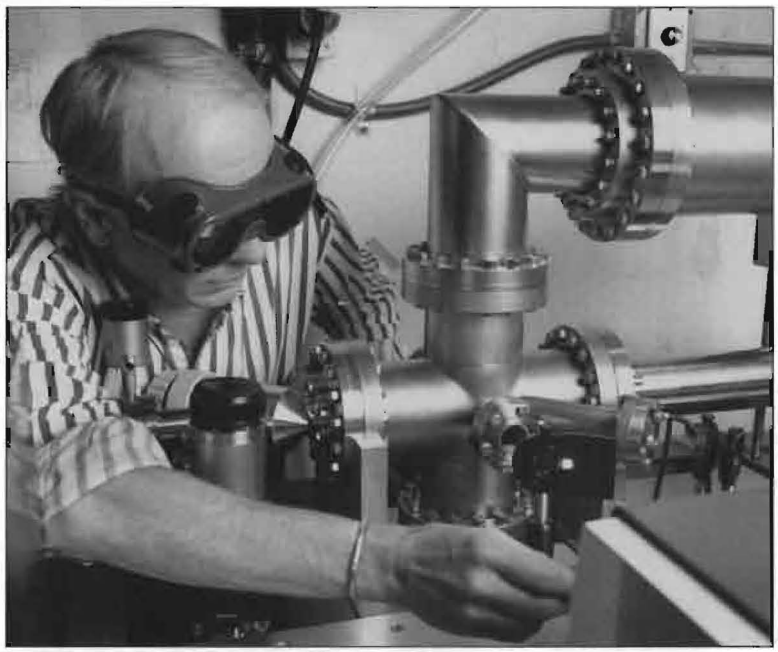
pothesis are in progress.

The University Of California Marine Bio-Optics Group (UCMBO) is an MRD intercampus group directed by Dr. Raymond C. Smith at UC Santa Barbara with Scripps facilities coordinated by Karen S. Baker. The group uses experimental work at sea and modeling to study theoretical and applied problems in marine optics. UCMBO research includes an interdisciplinary program to clarify the optical variability of the upper mixed layer of the ocean. A deep-sea mooring with a string of physical and optical sensors was deployed in the North Atlantic (60°N, 21°W). This particular location has one of the strongest seasonal changes in mixed layer depth in the world's ocean.

UCMBO scientists are assessing the links between ocean optics and wavelength dependent productivity of marine phytoplankton. They are also focusing on the ultraviolet (UV) radiation reaching the earth's surface and its impact on aquatic environments. The Antarctic is now experiencing a 30-50% springtime loss of its stratospheric ozone layer. This large change occurs over periods of only a few days. As a result, there is interest in assessing the impact of enhanced ultraviolet radiation levels on aquatic organisms.

Dr. Jeffrey L. Bada's research group is using state-of-the-art analytical techniques, especially laser-based methodologies in analyses of various organic components in natural systems. They are detecting extraterrestrial amino acids (ones that have no or limited biological occurrence) and polycyclic aromatic hydrocarbons (nonbiological compounds that are produced on the earth from combustion processes) in sediments, ocean waters, and polar ices. Analytical methods used in these studies include highly sensitive laser-induced fluorescence (LIF) measurements and two-step laser desorption/laser ionization mass spectrometry (L^2MS).

Dr. Bada's group found that extraterrestrial amino acids—a-aminoisobutryic acid and racemic isovaline, two amino acids common in certain meteorites—are present in Cretaceous/Tertiary boundary sediments. This geologic boundary is believed to be associated with the collision of a large comet or asteroid with the earth. The presence of nonbiological meteoric amino acids in the boundary sediments suggests that amino acids and other organic compounds can be added to the earth's surface by bolide impacts. Their findings have important implications concerning the source of the organic material required for the origin of life. The search for extraterrestrial amino acids in other systems on the earth is continuing.



Dr. Bada uses a laser based detection system to measure polyclic aromatic hydrocarbons.

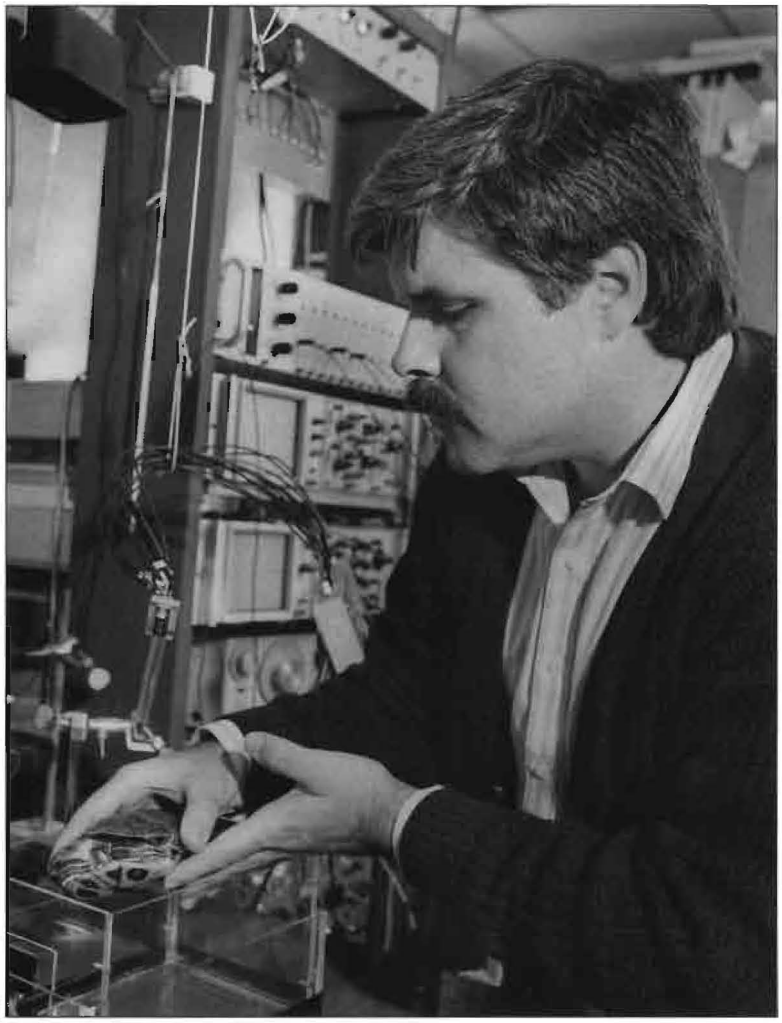
The scientists in Dr. Bada's laboratory are analyzing polycyclic aromatic hydrocarbons (PAHs) using L^2MS. They found that these compounds are ubiquitous on the surface of the earth. They have also conducted studies on the fluorescence of seawater using a laser-based detection system. These results have provided new insights into the cycle of organic carbon in the oceans, which is important in the understanding of the global carbon cycle.

Dr. Toyoaki Nogami and his group are conducting research on geomechanics and geotechnical engineering. They are working on numerical modeling of offshore pile foundations for earthquake response analyses. Dr. Jian R. Tao is investigating the behavior of seawalls subjected to earthquake ground shaking. He is considering liquefaction effects in the backfills, nonlinear stress-strain soil behavior and water-wall-soil interaction. A finite element method was first developed for the numerical evaluation considering all of these factors.

Dr. Maria Vernet's group concentrates on pigments to study the ecology and physiology of marine algae. Plants synthesize pigments to absorb visible light. Light and carbon dioxide are the first steps in the synthesis of organic matter, the beginning of the marine food web. In the ocean, phytoplankton are able to grow in well illuminated areas near the ocean surface. These unicellular algae are floating in the water, subjected to mixing, and have no control over the depth and the light intensity to which they are exposed. The algae are highly plastic and are able to adapt in a matter of minutes to hours to new light conditions. Thus by studying the type and concentration of the pigments, Dr. Vernet can clarify the mechanisms of the adaptation of marine phytoplankton to their environment.

Phytoplankton abundance can be estimated by studying the distribution and abundance of chlorophyll in the ocean. Some very small algae (less than 1 micrometer) from tropical waters do not have chlorophyll *a* but a very similar compound. This alternate form of chlorophyll *a* was studied during a recent cruise off Hawaii. Scientists estimated that these small algae contributed to roughly 30% of the total primary production in the area.

Neurobiology Unit



Dr. James C. Prechtl lowers a turtle into the water for orienting tests.

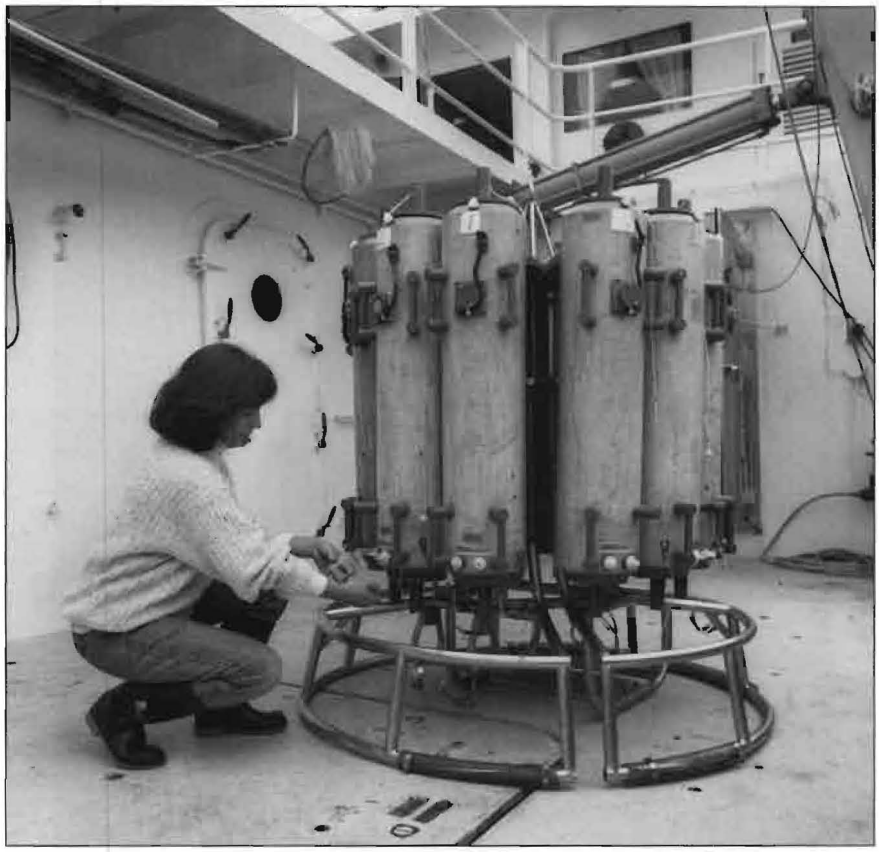
THE NEUROBIOLOGY UNIT, founded in 1967, links Scripps and the UCSD School of Medicine in the Marine Biomedical Program. Unit scientists, including faculty members, postdoctoral associates, and graduate students, focus on the structure and function of the nervous system in animals—particularly bony and cartilaginous fishes.

Drs. Theodore H. Bullock and James C. Prechtl and colleagues are studying the evolution of higher brain functions. They are finding the brain waves in rays and other lower vertebrates that accompany surprise or expectation.

Drs. R. Glenn Northcutt and Helmut Wicht are examining the connections of the forebrain in hagfishes and lampreys. They are seeking the features of these brains that were probably present in the earliest vertebrates. They are searching for the regions responsible for the dramatic increase in the size of the hagfishes' forebrain.

Drs. Shaun P. Collin and Northcutt are comparing telencephalic organization in squalomorph and galeomorph sharks, to determine what changes occur in the visual areas associated with telencephalic enlargement. Drs. Northcutt, Bernd Fritzch, and collaborators are studying the ontogenetic development and organization of the receptors and nerves of the lateral line system in amphibians and non-teleost fishes. They also are beginning a similar analysis of teleost fishes.

Physical Oceanography Research Division



Dr. Lynne D. Talley, a chief scientist on the first WOCE expedition, takes measurements from a CTD rosette.

INVESTIGATORS IN THE Physical Oceanography Research Division (PORD) study a range of problems in all branches of physical oceanography and related aspects of marine meteorology. This report reviews PORD activities in the World Ocean Circulation Experiment followed by more detailed descriptions of two selected research programs.

World Ocean Circulation Experiment

The ocean, because of its enormous heat capacity, stores, transports, and slowly gives up the sun's heat over a much longer time than in the atmosphere. Thus, the ocean is an important regulator of the atmosphere, which is largely heated from below. The way the ocean stores and transports heat is quite complicated, and depends on: (1) the large-scale circulation, (2) deep-water formation in limited high latitude regions with consequent upwelling elsewhere in the global system, and (3) time-dependent eddies that are smaller than the general circulation. The overall response to changes in surface forcing, which would result from a greenhouse effect, is therefore difficult to model because of the many contributing parts of the system.

To improve our models of the long-term interaction of the ocean with the atmosphere and hence of climate, it is necessary both to understand the physical processes at work and to discover, as best we can, what the ocean is doing. Some of our questions include: What is the long-term mean response of the ocean to strong

winds and strong heating and cooling? How do the great gyres, their western boundary currents (such as the Gulf Stream and Kuroshio), and the complicated zonal equatorial currents become established? How and where can water cross the equator, as must happen in the Atlantic Ocean, given its observed northward heat transport?

A great deal has been learned during decades of ocean exploration. Recently there has been an explosion of progress in understanding the ocean's physical processes. An international World Ocean Circulation Experiment (WOCE) is under way to further the exploration and modeling of the ocean circulation and to obtain a comprehensive view of the ocean circulation in the 1990s. WOCE will be a benchmark for past and future studies, taking advantage of several new satellite missions.

Many PORD investigators have been involved in planning WOCE and are participating in observational programs with national and international scientists. The first U.S. WOCE hydrographic cruise aboard R/V *Thomas Washington* in the eastern and central tropical Pacific was led by Drs. Lynne D. Talley, James H. Swift, and Mizuki Tsuchiya. The basic hydrographic program will provide information on tropical currents down to the ocean bottom. This cruise is the beginning of a Pacific-wide study, which will be expanded to the Indian and Atlantic oceans. On the 1991 cruise, Dr. Russ E. Davis's Autonomous Lagrangian Current Explorers (ALACE) were deployed in the Pacific. Program instruments will provide basin-wide float tracks at about 1,500 m deep. Dr. P. Peter Niiler continued his surface drifter seeding of the Pacific Ocean, which is part of both the WOCE and Tropical Ocean Global Atmosphere (TOGA) programs. Researchers with the TOGA program are investigating the five-to-ten year fluctuations in the ocean and atmosphere, including the El Niño/Southern Oscillation.

Characterizing changes in the ocean circulation and its heat content is also part of WOCE. Drs. Warren B. White, David L. Cutchin, and Steven E. Pazan have long been involved in measuring changes in the upper Pacific Ocean's heat content through a large expendable bathythermograph (XBT) program on merchant vessels. This program has been expanded into the tropics for TOGA with real-time data return to monitor the development of El Niño events, and provide data for computer models of the tropical Pacific. Densely sampled XBT sections from merchant vessels can also be used to study changes in circulation and boundary currents.

Frank M. Delahoyde and James A. Schmitt prepare to launch a Gerard barrel during the first WOCE cruise aboard R/V *Thomas Washington*.

James Schmitt

Recently Drs. Dean H. Roemmich and Bruce D. Cornuelle initiated such a program in the western South Pacific and have described the mean and variations of currents between New Zealand and Fiji. This study is being expanded as part of WOCE to include the entire Tasman Sea, with its enigmatic western boundary current, and then the full Pacific Ocean, both with international cooperation. This project will be the only source of in-situ information on broad-scale changes in the Pacific circulation and will complement the satellite altimetry, which provides information on changes in the vertically integrated currents.

PORD investigators have long been carrying out research of the sort embodied by WOCE. For instance, intermediate and deep waters in the North Pacific have been shown by Dr. Roemmich to be circulating westward toward the western boundary, where they most likely must upwell. Flow at similar depths in the North Atlantic also appears to be westward with the deepest circulation, basically counterclockwise and following the topography, as described by graduate student Philip S. Bogden, in Dr. Davis's laboratory.

Recent research by Dr. Talley on intermediate water formation shows that the Okhotsk Sea is an important

site for ventilating intermediate depths in the North Pacific. In theoretical work related to ocean circulation, Dr. Paola Cessi has shown the circumstances under which a separating western boundary current creates a recirculation or a meandering current. Meridional heat transport across 11°N in the Atlantic has been estimated by Drs. Teresa Chereskin and Roemmich. They are using both standard hydrographic measurements and an innovative technique for determining the transport in the upper, directly wind-driven (Ekman) layer from acoustic Doppler current profiler data. Dr. Roemmich has shown that the deep waters in the central North Atlantic were warmed between the mid-1950s and mid-1980s. Dr. Swift found that the deep waters in the northern North Atlantic were freshened and cooled significantly between the early 1970s and the early 1980s. Both studies highlighted the relatively quick response, on the order of decades, of the deep North Atlantic to changes in atmospheric forcing.

Marine technicians launch a Gerard barrel during the WOCE cruise.

James Schmitt

Western Boundary Current Dynamics

The most powerful currents in the world's oceans are along the western boundaries of basins (the eastern coasts of continents). Peak velocities of 1 m/sec in the core of western boundary currents can be found, and a typical current transports about 20 million cubic meters per second. The Gulf Stream, which flows along the eastern coast of the United States from the Straits of Florida to Cape Hatteras in North Carolina, is the western boundary current most often studied. At Cape Hatteras the Gulf Stream leaves the coast and flows eastward into the North Atlantic. Because the current originates in the warm waters of the Gulf of Mexico, its temperature at Cape Hatteras is much higher than that of the surrounding atmosphere. The large temperature contrast found in the Gulf Stream separation region implies that the ocean loses a great amount of heat to the atmosphere, indeed the largest observed in the world's oceans.

Western boundary currents with characteristics similar to the Gulf Stream are found in every ocean, in both hemispheres, always pressed against the eastern continental margins. The main reason for these large currents has been known since the late 1940s. In the subtropical interior of the basins the wind drives a weak, broad equatorward flow that occupies the water column's top 1,000 m. Western boundary currents return poleward all the mass that has been driven southward in the interior. Because these return currents are confined to a longitudinal scale, which is much smaller than that of the interior flow, they are much swifter.

A swift Gulf Stream-like current flowing along a coast can dissipate the energy put into the ocean's interior by the wind through frictional stresses. Although the role of western boundary currents in the mass budget of the wind-driven circulation is clear, their role in the energy balance is not well understood. Clarifying the role of these currents in the energy budget of the wind-driven circulation is the focus of Dr. Cessi and colleagues Dr. Glenn R. Ierley and Dr. William R. Young.

Because friction is very small, efficient energy dissipation occurs only at small scales, thus the question of how large-scale oceanic flows achieve the energy balance is not a trivial one. By studying simple process models Dr. Cessi and collaborators have isolated two mechanisms that enhance energy dissipation in western boundary currents.

One way the current augments energy dissipation is to set up a recirculating gyre with enhanced transport. Recirculation increases dissipation by squeezing the current against a solid boundary or against an-

other counterrotating gyre, thus reducing the cross-stream width of the current to a scale where friction is effective. This 'mode' of dissipation is achieved when a current flows east-west. Indeed, two recirculating gyres are observed to flank the Gulf Stream to the north and south as it flows eastward, after separation at Cape Hatteras. The combined transport of the Gulf Stream and the eastward flow of the recirculating gyres is about 200 million cubic meters per second compared with the current transport at the Straits of Florida, which is about 30 million cubic meters per second.

Another way for a western boundary current to enhance dissipation is to increase its length, so that friction, while small, can act for a long distance. Thus the current overshoots to the north along the coast, and then turns south in a large oscillation before rejoining the interior flow. In this way it forms a loop current along the coast. This 'mode' of dissipation is preferred when the flow can proceed unimpeded along a north-south coast. Several currents in the Southern Hemisphere exhibit 'overshoots,' for example the East Australian Current in the Coral Sea and the Agulhas Current in the South Indian Ocean. In the case of the Agulhas Current the overshooting loop exports tracers (such as salt and oxygen) with concentrations typical of the Indian Ocean into the South Atlantic. The export of salty water from the Indian to the Atlantic is thought to be crucial for the formation of Deep Water in the North Atlantic. In turn Deep Water formation presently appears an essential ingredient of the climate balance.

From the observational perspective, the distinction between the two 'modes' of energy dissipation is important, because in one case the transport of the current is greatly enhanced, while in the other, properties might be carried great distances from the site of formation.

Flows Through Straits and Channels

Flow through a narrow channel that connects two large basins is a common oceanographic feature, and the channel often controls the rate of flow between the basins. Flow through a strait, such as the Strait of Gibraltar, is of this type. Other examples include flow in estuaries and through gaps between islands and mid-ocean ridges. A variety of factors contribute to the complexity of these flows. Typically the ocean is a continuously stratified body of water, with the density varying from heaviest fluid at the bottom to lightest at the top and the currents are often time-dependent, varying with the tidal cycle. The geometry of the passage that controls the flow is complex, consisting of a channel that changes both in width and in depth. On geophysical scales, the rotation of the earth can also affect the flow.

Studies of flow through constrictions typically concentrate on only a few of these variables. Drs. Laurence Armi and Richard J. Williams have been studying the flow of continuously stratified fluids through a constriction to learn how the constriction controls both the rate at which fluid can flow and the vertical structure of the flow. They have focused on flows through a horizontal contraction with a flat bottom. The flows have been steady rather than time dependent and have been unidirectional rather than the bidirectional exchange flows found in many oceanic applications.

These simplifications allowed the development of a hydraulic theory that considers the interaction of buoyancy forces caused by the varying density of the fluid and the inertial forces created by the relatively high speed of the flow. An important result of the theory is that, in this simplified geometry, there are strong constraints on the possible flows that can emerge from a large, stagnant basin of fluid and proceed through a narrowly constricted channel. These constraints arise because of the interaction between the moving fluid and the internal gravity waves that the continuous stratification can support, and they are a generalization of the idea of hydraulic control that has long been used in engineering problems involving open channel flow of a homogeneous fluid.

A facility for laboratory experiments has been constructed and experiments have been carried out to confirm the major aspects of the theory. A narrow, flat-bottomed channel, 10 cm wide, was connected to a large reservoir 125 cm x 250 cm x 24 cm. The channel narrowed gradually to 2 cm and then opened up again to its full width. The reservoir and channel were filled with a salt solution with a vertically varied density. Fluid was slowly withdrawn from the channel end, so fluid left the reservoir and flowed through the narrow contraction. This withdrawal was made by pumping fluid from the channel at a constant flow rate, and no measurements were made until after any startup transients had died out.

Two techniques were used for flow visualization. As the reservoir was filled, red food coloring was used to dye various levels in the tank, so when the fluid was stationary, there was a series of equally spaced horizontal red bands, each marking a different density level. As the fluid flowed through the contraction, the density surfaces moved up or down, and the dyed bands allowed the displacement of the density surfaces to be observed. In the second technique small crystals of potassium permanganate were dropped into the channel. As they fell, they dissolved and left a vertical trail of purple dye. This streak was then swept downstream by the flow, and photographed a short time after the crystals were dropped giving a picture of the vertical structure of the velocity field. Quantitative measurements of the velocity field were made by seeding the fluid with metallic paint pigment, illuminating these particles with a vertical sheet of light and then taking a time exposed photograph of the particles. This gave a streak photograph from which researchers could determine the velocity field and compare it with the theory.

These experiments have added to the understanding of the flow of continuously stratified fluids and the control of flows in narrow passages.

Physiological Research Laboratory

Dr. Gerald L. Kooyman glues a transponder to the feathers of a Ross Sea emperor penguin as part of a satellite tracking study to determine foraging range.

SCIENTISTS IN THE Physiological Research Laboratory (PRL) conduct field and laboratory investigations of the biochemical, physiological, and behavioral adaptations of aquatic and terrestrial animals. How these adaptions have enabled marine organisms to survive, flourish, and specialize for extreme ranges of temperature, pressure, and salinity found in ocean habitats is their focus. The research of three PRL investigators is described.

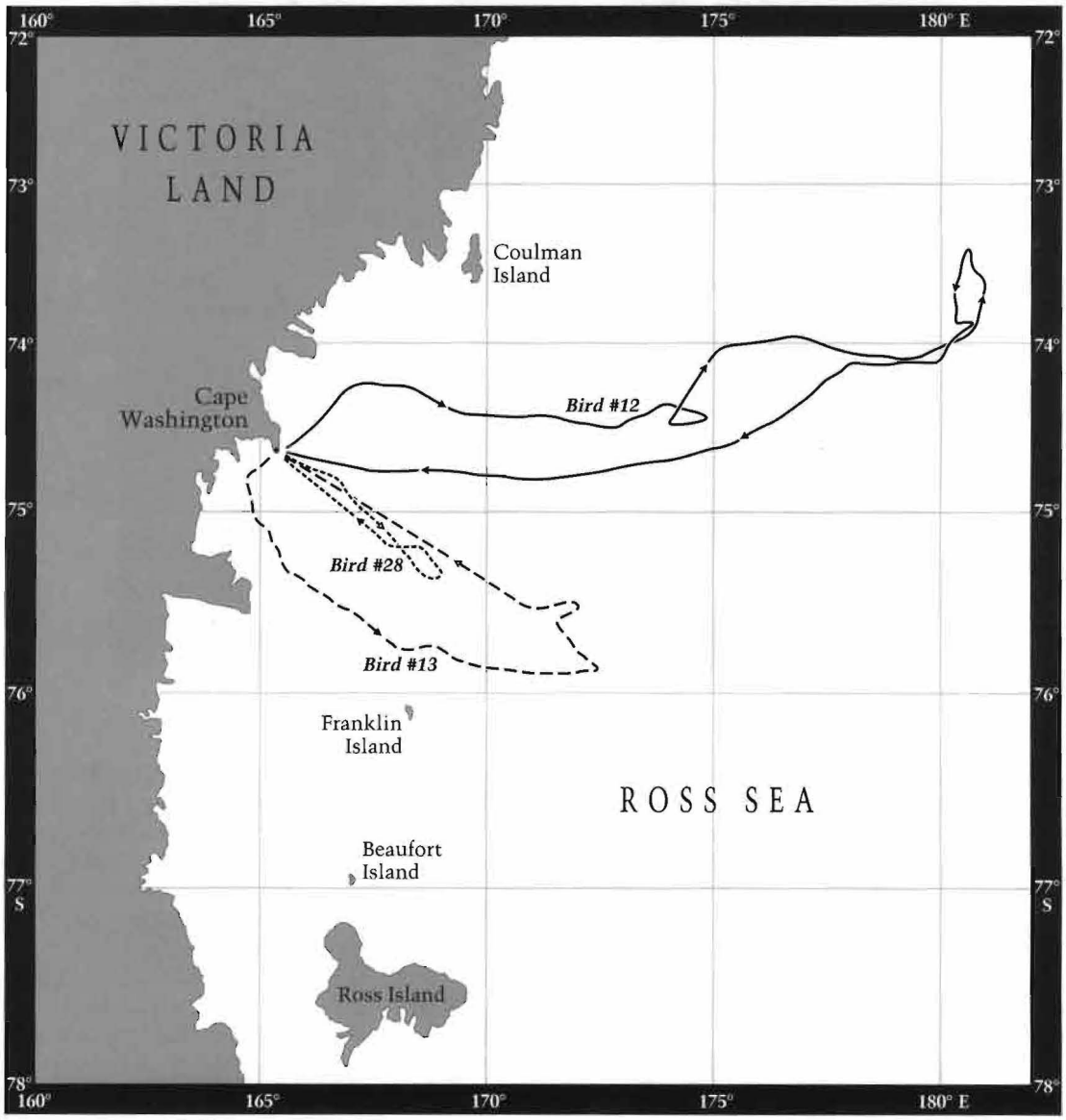
Dr. Jeffrey B. Graham and graduate student Heidi Dewar transported the Scripps water treadmill to the National Marine Fisheries Laboratory in Honolulu, Hawaii, for a one-year study of tuna swimming performance. This research provided the first, long-term measurements of tuna swimming metabolism in relation to swimming speed, water and body temperature, and body size. Thermoregulatory experiments demonstrated the tuna's ability to regulate their rates of heat gain and loss in response to water temperature and to rapid temperature changes occurring during vertical movement. In conjunction with global climate change studies, graduate student Peter A. Fields has developed a computer-controlled thermal shuttle box to test the water temperature preferences of three species of the local bass (*Paralabrax*).

Research in Dr. Edvard A. Hemmingsen's laboratory is focused on gas bubble formation in liquids and organisms. The identification of physical factors that govern the spontaneous nucleation of bubbles and their stabilization and growth are under

study. Currently, the effect of dissolved carbon dioxide on the nucleation of bubbles is being investigated. How bubbles may form in animals, including humans, is important in understanding conditions of decompression.

Dr. Gerald L. Kooyman continued a multi-year study of emperor penguins' natural history. This year, in collaboration with French scientists, the first satellite-tracking of penguins was completed. Routine foraging range for the birds was determined to be 200 km away from the breeding colony during feeding trips of 10 days. Also, underwater observations were obtained of the tactics used by emperor penguins to avoid leopard seals, their major predator. Drs. Kooyman and Paul J. Ponganis visited six Ross Sea emperor penguin colonies to assess habitat characteristics. Their observations are of interest because they include colonies ranging from the largest to the second smallest emperor colony. Their studies may help determine the habitat needs of this species.

Satellite tracks of three emperor penguins. Each bird was nurturing a chick at the Cape Washington breeding colony. The birds had left the colony to obtain food for themselves and the chicks.



Center for Coastal Studies

Mark Freeman

Boat is lowered from *Almirante Othon P. Blanco* into the harbor of Veracruz for instrument deployment.

SCIENTISTS AT THE Center for Coastal Studies (CCS) investigate shallow seas, straits, and open coastal areas. Currently their main focus includes circulation studies with application to understanding and managing anthropogenic activities in the coastal area, surface gravity wave studies designed to describe processes that control the circulation in very shallow depths, and sediment transport processes. CCS scientists collaborate with biological oceanographers in the Marine Life Research Group who are also working on coastal zone projects.

One CCS project is featured each year. This year, a study by Drs. Nancy A. Bray and Clinton D. Winant, and graduate student Guillermo Gutierrez De Velazco on the circulation on the southern continental shelf of the Gulf of Mexico is described.

The Gulf of Mexico is the principal marginal sea bordering the continental United States and is a major source of the hydrocarbons used in this country. These are derived from both United States territorial waters and from Mexican production areas. The Gulf of Mexico is a prototypical marginal sea, thus the results of this study may apply to other similar seas, which are more distant or difficult to study. Several research projects are being carried out on the United States side of the gulf. This project was designed to complement and enhance those projects by obtaining comparable observations from the Mexican portion of the gulf. This study is being conducted in close collaboration with Mexican oceanographic institutions,

Scripps and Mexican scientists check current meters deployed in the Gulf of Mexico.

Mark Freeman

notably the Oceanographic Directorate of the Mexican Navy and the Mexican Tide Service, part of the Geophysics Institute of the Universidad National Autonoma de México.

The shelves bordering the Gulf of Mexico ranged from a width of a few kilometers near Veracruz, to several hundred kilometers over the Campeche Bank and the West Florida Shelf. These shelves have almost any orientation relative to the prevailing easterly trade winds. Regions of shelf strongly influenced by local runoff are interspersed with regions of little or no buoyancy input. Both the Campeche Bank and the West Florida Shelf are influenced by the swift Yucatan or Loop current. There is evidence that wind stress affects the circulation of coastal waters either directly or remotely, through the mechanism of coastal trapped waves. Finally, shelf processes are expected to be influenced by the spin-down of eddies generated by the Loop Current.

Six meteorological stations, four current meter moorings, and three bottom pressure sensors were deployed between Tuxpan, Mexico, and Isla Mujeres spanning the entire width of the southern half of the gulf. The observational array will remain through September 1993. Maintenance and inspections will be conducted every six months with support from the Mexican Navy. Each minute the instruments sample the: (1) wind speed and direction, (2) air temperature and barometric pressure for the meteorological stations, (3) two components of current and temperature at 10 m and 75 m beneath the surface for current meters, and (4) sea level and water temperature from the pressure sensors.

The atmospheric observations acquired to date show that the wind field can be divided into two spatial patterns. In the northwestern gulf, winds are strongly influenced by cold air outbreaks that occur most frequently between October and May. These events can last for several days and have a longshore orientation. In contrast, off the Yucatan Peninsula and the Caribbean Sea, mean winds are oriented toward the west, and the region is dominated by events with periods of two weeks with a rotary character.

Currents measured on the continental shelf show the expected response to this vigorous atmospheric forcing, but in addition, very strong currents have been measured off Isla Lobos, with amplitudes in excess of 1 m/s. These currents fluctuate yearly and are thought to be associated with Loop Current eddies that can impinge on the shelf in this area.

At periods longer than one month, air and sea temperature records have a similar behavior, with the water warmer than the air most of the time, and following the annual cycle of heating and cooling. Through much of the winter, near surface water temperatures seem relatively insensitive to the cold air outbreaks.

This cooperative project with Mexico ensures that observations over the entire Gulf of Mexico will be acquired in a synoptic fashion. Drs. Winant and Bray expect that the results will be analyzed jointly by scientists working in both countries.

Climate Research Division

Dr. John O. Roads loads computer tapes needed for his meteorological anaylses.

THE PROSPECT OF global climate change caused by humans, particularly through enhancing the natural greenhouse effect, has stimulated many scientific investigations throughout the world. In the Climate Research Division, physical oceanographers and meteorologists study a range of phenomena that underlie both natural and man-made climate variability. Their goal is to measure, model, understand and ultimately predict many aspects of climate. Their main tools are computers, used to analyze observational data and to develop and exploit numerical models for simulating and forecasting climate change.

The study of natural climate variability is closely linked to understanding the consequences of an increased greenhouse effect. The climate of the twenty-first century is likely to be different in many significant ways from that of recent decades. The differences will almost certainly not appear as a simple global warming. Instead, they will involve changes in oceanic and atmospheric circulation, the hydrological cycle, sea level, snow and ice cover, and several complex phenomena, such as El Niño.

Dr. Daniel R. Cayan's work involves air-sea interaction and the influence of climate variability on continental surface hydrology. He is studying how monthly and longer-scale fluctuations in atmospheric circulation can affect the exchange of heat and moisture between the atmosphere and the ocean. His studies help clarify observed variations in temperature and salinity in both the Pacific and the Atlantic ba-

sins. Dr. Cayan and colleagues are also investigating the influence of climate variability on the surface hydrological budget over North America. In particular, they analyze the sensitivity of Sierra Nevada watershed hydrology to climate variability.

Drs. Shyh-Chin Chen and John O. Roads, working with Scripps graduate students and colleagues at the Los Alamos National Laboratory, have developed computational models of several aspects of the global hydrological cycle. They used these models to examine the predictability of annual and seasonal average global precipitation, evaporation, and atmospheric water vapor transport. Drs. Cayan, Chen, and Roads used an atmospheric general circulation model to create century-long simulations. They analyzed these simulations to determine how global variability is associated with regional extremes in the hydrologic cycle such as the current California drought.

Dr. Roads studies model simulations of the western U. S. climatology.

Dr. Kyozo Ueyoshi has developed a high-resolution mesoscale model that can extend these studies to finer spatial scales. Mesoscale models can resolve phenomena such as the effect of the Sierra Nevada and the coastal ranges in reducing precipitation in the Great Basin of the western United States. Drs. Chen, Roads, and Ueyoshi are using this model to study how regional patterns in the hydrological cycle may be inferred from the large-scale patterns simulated by global climate models.

Drs. Arthur J. Miller, Tim P. Barnett, and Nicholas E. Graham are collaborating in numerical ocean circulation modeling research with colleagues at the Max Planck Institute for Meteorology in Hamburg. They are using an ocean model with an isopycnic (constant density) coordinate system and an embedded surface mixed layer to better understand the physical processes involved in El Niño events. This model has been coupled with an atmospheric model to produce experimental El Niño predictions. Dr. Barnett demonstrates that the El Niño phenomenon involves a nonlinear interaction between two distinct modes of natural climate variability, one having a time scale of five to six years, and the other being the well-known quasi-biennial oscillation.

Working with German scientists, Dr. Barnett has explained the slow eastward drift of sea surface temperature anomalies associated with El Niño. This phenomenon may be caused by internal ocean processes and local air-sea feedbacks in which the atmosphere plays a passive role. These studies also show that air-sea exchanges in the equatorial Pacific during El Niño tend to regulate or damp ocean warming rather than to force it.

Dr. Warren B. White led an effort to produce near-global maps of sea-surface temperature and upper ocean heat content for each bimonthly period of a ten-year interval from 1979 to 1988. Each map is based on about 3,000 temperature profiles made by expendable bathythermographs deployed from a variety of commercial, naval, and research vessels. Statistical analysis of this unique data set revealed the global nature of the El Niño events in 1982-1983 and 1986-1987. The subtropical and subarctic gyres in the Pacific and Atlantic, as well as the tropical gyres in the Indian Ocean, all demonstrate fluctuations on the El Niño time scales over this ten-year period.

Dr. Alejandro Pares-Sierra developed a high-resolution mesoscale ocean model and is using it to investigate the response of the California Current system to global climate change caused by an enhanced greenhouse effect. Numerical experiments with this model show that during the 1982-1983 El Niño, most of the anomalous circulation in the California Current region was attributable to remote forcing from the equatorial region. Enhanced local wind-driven upwelling produced only a relatively minor contribution. These studies demonstrate that remote forcing and local processes can interact either to reinforce one another and yield an enhanced response, or to cancel one another and suppress the response in the coastal North Pacific.

Drs. Sam F. Iacobellis II and Richard C. J. Somerville developed a novel diagnostic atmospheric model to study cloud-radiation interactions and related atmospheric processes. Their model is designed to use atmospheric observations to validate and to improve the treatment of these processes in global climate simulations. The diagnostic model includes parameterized vertical atmospheric transports by convection and turbulent mixing, as well as solar and terrestrial radiative transfer with interactive clouds. When forced with observational data, the model produces complete heat and water budgets in an atmospheric column, including vertical profiles of temperature and humidity, together with surface energy budget components.

Geological Research Division

Dr. Bruce L. Deck monitors a methane combustion in Dr. Wahlen's laboratory.

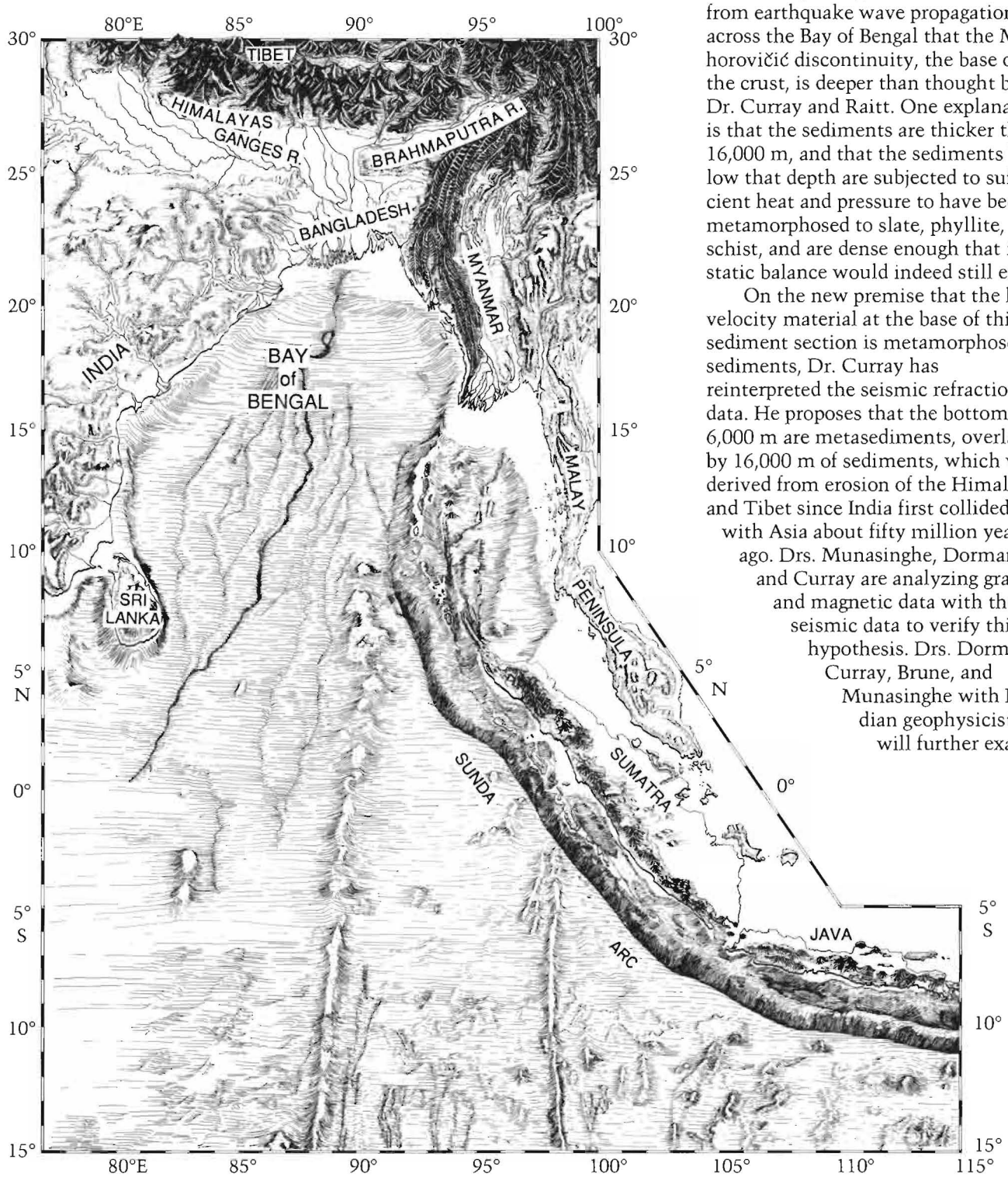
RESEARCH IN THE Geological Research Division (GRD) spans fields from marine geology and geophysics, satellite altimetry, mantle and crust evolution, ocean and climate history, isotope geology and geochemistry, and marine geochemistry to atmospheric and planetary chemistry and isotopic composition and evolution. Selected GRD research is described here.

Marine Geology and Tectonics

Most of the great accumulations of sediment in the world lie at continental margins, where large rivers deposit sediments derived from continental erosion. The sediment piles beneath the Mississippi and Niger river deltas are examples. The rivers carrying the greatest sediment loads in the world today, however, have their headwaters in the still-rising Himalayan Mountains and the Tibetan Plateau—the area uplifted by the continuing collision of India with the rest of Asia. Two of the greatest of these rivers are the Ganges and Brahmaputra, which are confluent in Bangladesh, and debouch their sediments to the Bengal Fan in the Bay of Bengal. Drs. Joseph R. Curray, LeRoy M. Dorman, James N. Brune, and Tissa Munasinghe, and Russel W. Raitt are reexamining geophysical data from this area. They conclude that it is probably the thickest sediment accumulation in the world today, >22,000 m.

A decade ago, Dr. Curray and Raitt, and others, interpreted seismic refraction measurements at sea, and showed that there is >16,000 m of sediment beneath the Bangladesh conti-

Physiographic diagram of the northeastern Indian Ocean and adjacent land areas, drawn by Jo P. Griffith from the data of Frans J. Emmel and Dr. Joseph R. Curray.



nental shelf. This was one of the thickest sediment columns in the world, and theory at the time suggested that it was the maximum sediment thickness that could accumulate on oceanic crust and remain in isostatic balance.

Subsequently, Dr. Brune observed from earthquake wave propagation across the Bay of Bengal that the Mohorovičić discontinuity, the base of the crust, is deeper than thought by Dr. Curray and Raitt. One explanation is that the sediments are thicker than 16,000 m, and that the sediments below that depth are subjected to sufficient heat and pressure to have been metamorphosed to slate, phyllite, or schist, and are dense enough that isostatic balance would indeed still exist.

On the new premise that the high velocity material at the base of this sediment section is metamorphosed sediments, Dr. Curray has reinterpreted the seismic refraction data. He proposes that the bottom 6,000 m are metasediments, overlain by 16,000 m of sediments, which were derived from erosion of the Himalayas and Tibet since India first collided with Asia about fifty million years ago. Drs. Munasinghe, Dorman, and Curray are analyzing gravity and magnetic data with the seismic data to verify this hypothesis. Drs. Dorman, Curray, Brune, and Munasinghe with Indian geophysicists will further exam-

ine this hypothesis by running new, longer refraction lines with the Scripps ocean bottom seismometers.

Dr. Edward L. Winterer and graduate students MaryAnn Lynch and Robert J. Van Waasbergen are analyzing data and samples taken during central and western Pacific cruises.

Work on the *en-echelon* ridges in the eastern equatorial Pacific shows that the ridges are composed of altered alkali basalts and are at least 40-60 million years old. They have modern magnetic polarity, for which there is no explanation other than viscous remanent magnetization. The ridges show a combination of tensional and unstressed features, with the tensional features greatest in the longest and narrowest ridges. The longest ridges resemble elongate rift zones, with few subsidiary seamounts beyond a central high. The set of ridges describes a gentle arc about 2,000 km long, around a pole at about 40°N, 150°W.

Work on the Early Cretaceous reef-capped, sunken seamounts of the northwest Pacific shows that most of the volcanic foundations were emplaced in a short time, about 120 million years ago. Nearly the same time as the formation of the immense submarine volcanic plateau, the Ontong Java Plateau was formed near the equator in the westernmost Pacific. This volcanic episode—one of the largest in earth history—is associated temporally with major changes in dissolution levels in the world's oceans. This episode also may be responsible for a rapid sea level rise of several tens of meters and with a substantial increase in CO_2 in the oceans and atmosphere.

The reefs, which formed atolls with a central muddy lagoon and a perimeter reef consisting of large rudistid bivalves and minor amounts of coral, grew vigorously and kept themselves at sea level while their foundations subsided. About 100 million years ago, while some of the reefs were already in the process of drowning, a regional uplift forced the reefs up as much as 200 m above sea level, where rainwaters eroded the limestone into a landscape of sinkholes and broad solution basins. By about 90 million years ago, the islands had sunk once more beneath the sea, and pelagic ooze accumulated as a final cover.

During the year, scientists sampled a number of these ancient reefs from drilling vessel *Joides Resolution*. Two more 2-month campaigns of drilling are scheduled for 1992.

Ocean Productivity and Climate History

Scientists in Dr. Wolfgang H. Berger's laboratory study deep-sea sediments. They focus on calcareous ooze of the late Neogene age from the Ontong-Java Plateau. Their studies, in conjunction with University of Bremen colleagues, are part of the Ocean Drilling Program. They are working on reconstructing productivity fluctuations for the western equatorial Pacific, covering the last few million years. Stable isotope records of planktonic and benthic foraminifera, as well as abundance measurements of diatoms and benthic foraminifera, are used in their determinations.

Benthic foraminifera studies by Dr. Juan Carlos Herguera show that the productivity levels of western equatorial Pacific waters were significantly higher during glacial time than today. A paleoproductivity record for the last 450,000 years indicates that the intensity of ocean mixing played a crucial role in the observed changes. The bathyal thermocline and nutricline deepened to 2,000 m during the last glacial interval, probably as a result of a change in deep-sea circulation and ocean productivity. However, Dr. Carina B. Lange found the productivity increased during glacial periods, while the diatom flux and quality of preservation of diatom shells decreased. During glacial periods it appears that the ocean's undersaturation of silica was greatly increased, presumably because of increased opal deposition in the continental margins.

Drs. Arndt Schimmelmann, Lange, and colleagues worked on laminated sediment cores from the Santa Barbara Basin. They are attempting to reconstruct the history of upwelling from 1450 AD to the present, based on microfossils and geochemical parameters. Fossil, geochemical, and historic evidence links the 1835 eruption of the Nicaraguan volcano Cosigüina to unusual stormy weather off southern California. This resulted in dramatic short-term sedimentation changes in the Santa Barbara Basin.

Using the same sediment cores, Drs. Schimmelmann and Mia J. Tegner correlated the isotopic composition of dated sedimentary organic carbon with historically documented El Niños and other severe weather events from 1844 to 1987. Severe weather events lead to the temporary deterioration of the locally abundant ^{13}C-enriched kelp forests, thereby liberating isotopically heavy carbon for incorporation into the sediment. Diatoms, used as proxies for productivity reconstructions, reveal long-term trends of this ecosystem and relate to the strength and frequency of major El Niño events as well as to Pacific-wide climatic change.

Dr. Ute C. Herzfeld develops and applies geostatistical methods to geophysics and oceanography. In cooperation with Dr. Berger and Joseph L. Reid, she constructed a new phosphate-based productivity map using map comparison techniques. The nature of the topography of newly formed sea floor is being investigated by Drs. John A. Orcutt and Herzfeld. Dr. Herzfeld used variography to show that the sea floor near ocean ridges is not self-similar, but is an expression of scale-dependent structural and sedimentological processes. Other collaborative topographic-geophysical studies were done on Juan de Fuca Ridge, as well as in the Weddell Sea, on the origin of Wegener Canyon.

Dr. Devendra Lal, in collaboration with Dr. Farooq Azam and graduate students Tong-Sup Lee and Eunjoo Barg, developed several new experimental approaches to study the principal biogeochemical questions in recycling of nutrients. They are using cosmogenic and radiogenic nuclides as tracers to investigate recycling of nutrients, especially phosphorus, in the surface ocean waters, and export of carbon from the surface layers to the deep oceans. High sensitivity methods were developed to: (1) measure the concentrations of dissolved inorganic phosphorus (DIP) and dissolved organic phosphorus (DOP), (2) extract DIP and DOP from large quantities

David M. Allen moves an ice core in the freezer to prepare a sample for $^{13}CO_2$ isotopic measurement of the air in the core's bubbles.

(~m^3) of seawater, and (3) measure the activities of ^{32}P (half-life 14.3 days) in the DIP, DOP, and POP (particulate organic phosphorus: phytoplankton and zooplankton). They measured the cosmogenic radionuclide ^{7}Be (half-life 53.3 days) and the radiogenic radionuclide ^{234}Th (half-life 24.1 days) in the same water masses to interpret the common variables.

Several profiles of the nutrients and radionuclides were measured in the Southern California Bight during the past four years and show that the DIP pool has the highest $^{32}P/P$ ratio. Next in order are the phytoplankton, the zooplankton, and the DOP pools. These measurements yield the mean residence times of phosphorus in the pools. The data also provide insight to the role played by bacteria and sinking POP in the biodynamics. Eddy diffusivity and new production rates have also been estimated using the data.

The Global Cycle of Methane

Dr. Martin Wahlen's group focuses on atmospheric chemistry and isotopic composition of methane. They are elucidating the global cycle of the atmospheric trace gas methane, which is rapidly increasing in concentration. For this, the isotopic ratios of $^{13}C/^{12}C$ and D/H (by stable isotope ratio mass spectrometry), and composition of the radionuclide ^{14}C (by accelerator mass spectrometry) of methane, emitted from the major sources, are measured and compared to the isotopic composition of methane in the global atmosphere. The data indicate that four methane sources of about equal magnitude, contribute near 80% of the global annual methane production. These sources are: natural wetlands and tundra, rice paddies, ruminants, and fossil methane. The remainder is

UCSD student Derek Mastroianni and Dr. Martin Wahlen analyze an ice sample for CO_2 mixing ratio of air from bubbles.

thought to be methane from biomass burning, landfills, and possibly from termites.

Similar measurements were made on methane collected from the stratosphere. The data are used to elucidate the chemistry of methane destruction, and together with data on the ^{85}Kr concentration, yield estimates on the air exchange between the troposphere and stratosphere. In addition, the stable methane isotopes are used as tracers in mechanistic studies of bacterial methane production and destruction.

Dr. Wahlen is working on the chemical and isotopic reconstruction of past atmospheres from air enclosed in the bubbles of ice cores. The drilling of a 3,200 m deep ice core in central Greenland, should provide a 250,000 year record, spanning the last two climatic cycles. From this core Dr. Wahlen is establishing a high resolution record of CO_2 concentration in the enclosed air, which he will compare with the temperature signal provided by the $^{18}O/^{16}O$ and D/H ratios in the surrounding ice. This should lead to a better understanding of the climatic forcing of radiation by important trace gases. Attempts are being made to also measure the $\delta^{13}CO_2$ values in the enclosed air in order to try to understand the mechanisms by which atmospheric CO_2 concentration changes between glacial and interglacial times, and even on shorter time scales.

Oceanic Mantle and Crustal Geochemistry and Processes

Drs. James H. Natland and Peter F. Lonsdale, and a Duke University colleague participated in a series of submersible dives at Hess Deep in the eastern equatorial Pacific. The dive targets were steep scarps exposing

cross sections of the uppermost ocean crust through pillows and sheeted dikes into high-level gabbros that crystallized at the top of a magma chamber at the East Pacific Rise. Dr. Natland and graduate student Kristen Nilsson are studying the composition and mineralogy of rock samples obtained during the dives. The rocks represent the first samples of a magma-chamber complex in the Pacific with full stratigraphic control. They will provide a composite picture of the structure, degree of alteration, composition, and magnetic characteristics of the upper half of ocean crust produced at a fast-spreading ridge. The magnetic studies are being conducted by Dr. Jeffrey S. Gee.

Dr. Natland was co-chief scientist on Ocean Drilling Program Leg 132. On that leg a series of engineering tests of the newly developed Diamond Coring System (DCS) was carried out. Sites were cored on Sumisu Rift, a backarc basin west of the Bonin Islands, and on Shatsky Rise in the northwest Pacific Basin. The DCS is designed to recover high-quality cores from fractured or brittle rock in such environments as unsedimented spreading ridges or Mesozoic chert-chalk sequences in the Pacific.

Also in Dr. Natland's laboratory, graduate student Julie J. Dieu is studying the mineralogy of rock fragments (xenoliths) carried from the upper mantle during eruptions at southwest Pacific volcanic islands—Samoa, Tahiti, and the Marquesas. In collaboration with scientists from other institutions, they found the geochemical characteristics of the mantle rocks are revealed by combining textural information with electron-probe mineral analyses obtained at Scripps, and trace-element abundances of the minerals obtained using an ion microprobe housed at Woods Hole Oceanographic Institution.

Dr. Deck records results of experiment.

An understanding of the timescales associated with submarine magmatism is essential for constraining geophysical models of Mid-Ocean-Ridge (MOR) processes. However, direct observations of ridge-crest activity have been limited because of the relative inaccessibility of this harsh environment. This led Drs. Kenneth H. Rubin and J. Douglas Macdougall to study the timing of the ridge-crest volcanism through U-series disequilibrium in the basalts erupted there (MORB). Over the past five years, they have been examining problems ranging from the frequency of eruption, the time-scales of melting and melt migration, and the time-scale of MORB source chemical heterogeneity using various U-series tracers.

Drs. Rubin and Macdougall use ^{226}Ra-^{230}Th radioactive disequilibrium to date MORB. Their new technique relies on the large ^{226}Ra excesses first reported in MORB by this group in 1987. This isotope has a 1,620 year half-life and is enriched in MORB relative to its parent, ^{230}Th, by up to 500%. They calculate a rock age by comparing the ^{226}Ra excess observed today with its initial value estimated from the Ba and Th contents of the rocks. The former was measured using the analytical facility's newly installed Inductively-Coupled Plasma Mass Spectrometer (ICP-MS). The technique has provided useful age information about rocks from a variety of East Pacific Rise (EPR) locations which, when coupled with other observational data, will allow marine scientists to better understand ridge-crest volcanism.

Drs. Rubin and Macdougall are working on the relationship of the Th isotopic composition of MORB to other isotopic tracers such as $^{87}Sr/^{86}Sr$. The Th isotopic system is unique because it provides evidence about recent processes affecting mantle source chemistry. This is because of the relatively short half-life of ^{230}Th (75,200 years), compared to the parents of other isotopic tracers, such as ^{87}Sr and ^{143}Nd, which have half-lives of billions of years. Their Th isotopic studies on EPR MORB have shown that the MORB source is a dynamic environment, with a variety of recent

chemical processes creating variable ($^{230}Th/^{232}Th$) compositions in the erupted rocks, without any 'sensible' change in Sr and Nd isotopic ratios. By combining Th isotopic variations with the ^{226}Ra age data discussed above, they show that chemically distinct magmas can migrate from their source to the site of eruption (a distance of many tens of kilometers) in less than 1,000 years. This is a time-scale that is much faster than most recently suggested geophysical models of porous fluid flow in the mantle would predict.

Current work by Drs. Rubin and Macdougall includes U-series analysis of two sets of ridge-crest rocks, observed indirectly to have erupted recently. In collaboration with scientists at NOAA, University of Miami, and UC Santa Barbara, they are examining MORB from the Juan de Fuca Ridge, which erupted in the last decade and from the EPR at 9°N, which erupted in the last year. These samples will help to calibrate their ^{226}Ra dating system, and they may also clarify the ridge-crest magma generation processes at an even shorter time-scale than has previously been possible.

Dr. James W. Hawkins and graduate students Nilsson and Federico F. Florendo are studying island arc volcanic systems and backarc basins. Dr. Hawkins and Nilsson participated in an Ocean Drilling Program cruise to study the Lau Basin and Tonga Arc. Dr. Hawkins was a co-chief scientist of the cruise on this drilling leg, which included drilling six holes on a transect across the Lau Basin. Two additional holes were drilled on the Tonga Ridge, which forms the forearc of the Tonga Trench and arc system. Cruise scientists are clarifying the geologic history of the Lau Basin and its adjacent island arcs in order to improve existing models for backarc basin evolution. The drilling results have given insight to the evolution of the Lau Basin and Tonga Arc. Previous interpretations, based mainly on dredged samples and geophysical surveys had portrayed the entire Lau Basin as being a very young feature—less than 3 million years old—which had formed entirely by sea-floor spreading. The new data show that only the eastern part of the basin was formed by sea-floor spreading in the last 1.5 million years by extension of the crust in a manner more like continental rifting than sea-floor spreading.

A second project, involving Dr. Hawkins and Florendo, concerned the geologic history of the northern part of Luzon, Philippine Islands. Florendo spent 3 1/2 months mapping and collecting samples in two mountain ranges on Luzon. They will study the samples to trace the petrologic evolution of these mountain ranges from ancient island arc and backarc basin complexes to a micro-continent.

Geochemical Studies in the Isotope Laboratory

During the year scientists in Dr. Harmon Craig's Isotope Laboratory carried out research in several areas. A few of their projects are described here.

Krypton 81 Dating. Their most important achievement was the first use of this long-lived (213,000 year half-life) cosmogenic radioisotope for dating polar ice sheets. A ^{81}Kr age of 108,000 years was measured on ice upwelling at the base of the Trans-Antarctic Mountain Range in the Allan Hills Ice Field of Victoria Land. This work is the result of over a decade of collaborative research with the original atomic physics group at Oak Ridge National Laboratory on applications of Resonance-Ionization Time-of-Flight (RIS-TOF) mass spectrometry. Dr. Robert D. Willis, Atom Sciences, Inc., collaborated in this work.

^{81}Kr, formed in the atmosphere by cosmic radiation is, in principle, the ideal isotope for dating air trapped in ice in the age range from 50,000 to 1 million years. It has taken a decade of work and ~$2M to develop the method and even now heroic efforts are required. They excavated 224 kg of ice by chainsaw surgery from the surface of the ice field, extracted the trapped gases by vacuum melting, and finally obtained 0.009 cc of Kr (with 90,000 atoms of ^{81}Kr). ^{81}Kr was then enriched in two successive mass spectrometers in which ^{81}Kr atoms were selectively implanted in sapphire targets and then released for the next stage by laser zapping the targets. In the third and final stage, 9,300 ^{81}Kr atoms (in 5×10^6 stable Kr atoms) were counted by the RIS-TOF technique.

The calculated ^{81}Kr age is 108,000 ± ~28,000 years, which is in good agreement with estimates of the general age of the ice field made by Dr. Kunihiko Nishiizumi of the UC San Diego Chemistry Department, based on terrestrial ages of meteorites accumulating on the ice surface. Although the uncertainty in this age is rather large, what is important is that, for the first time, they have a *real number* for the age of an ice sample more than 50,000 years old. The ^{81}Kr age is the only method known that can date air in ice older than 50,000 years: this result is thus only the first of what will someday be the standard method for the chronology of polar ice.

It is interesting, and possibly amusing to some, that support for this work has been discontinued by the funding agency. This took place just before the ^{81}Kr age was obtained, on the basis of a funding agency's declaration that the Allan Hills ice could *not* be as old as indicated by Nishiizumi's meteorite residence times, because it was 'well known' that the ice was considerably younger. Science historians will be intrigued to note that this attitude is precisely reminiscent of the days when radiocarbon was in its infancy and self-appointed experts on Pleistocene chronology insisted that the radiocarbon ages were wrong. Unfortunately the wisdom of the 'experts' ceases to be amusing when used to stop funding of new science.

Gravitational Separation of Gases and Isotopes in Polar Firn. Recently Dr. Craig's group showed that $^{15}N/^{14}N$ and $^{18}O/^{16}O$ isotopic variations are observed in polar ice cores and are explainable by fractionation effects of gravitational equilibrium in the gases in the firn. However, separation by effusional losses could also cause the observed effects. This work has continued with Dr. Roger C. Wiens using rare-gas isotopes with large mass differences, to establish which of these processes is responsible.

For this work they used a new mass spectrometer recently added to

the Isotope Laboratory: a 54-cm effective radius, static-analysis and triple-collecting five-collector machine, designed by Dr. Craig and Dr. Kurt Marti of the UC San Diego Chemistry Department and built for them by VG as a 'VG5440' version of their 5400 machine. They measured $^{84}Kr/^{36}Ar$ ratios in Greenland ice core samples: for this mass pair the ratio enrichment versus air will be twice as large for gravitational separation as for effusion. The Kr/Ar ratio in the ice is 13.3 per mil greater than atmospheric, and corresponds to the effect predicted for gravitational separation. That is, *the krypton concentration in air trapped in the Greenland ice sheet is fully 1.5% greater than in the free atmosphere.* This is the largest observed variation in permanent gas concentrations in the atmosphere below the thermosphere, i.e. below an altitude of ~100 km, where molecular diffusion again begins to affect the mixing ratios of atmospheric components. Thus they have shown that there are actually *two regimes of molecular diffusion-dominated mixing in the atmosphere*: the upper atmosphere above the thermopause, as already known, and the firn layers of the permanent ice caps of Greenland and Antarctica, approximately the lowest 100 m of air in the regions of the polar troposphere.

Helium Jets and the Deep Pacific Circulation. The complete Pacific section on 135°W from Dr. Craig's HELIOS Expedition is the first detailed section for ^3He through the sub-equatorial zones of both hemispheres. It proves the reality of a second, northern, ^3He jet that had been suspected from a single point in the GEOSECS data. The southern ^3He 'plume jet' originates on the East Pacific Rise (EPR) at 13°S and was described by Drs. John E. Lupton and Craig in 1981 in a zonal section along its core. It is now matched almost exactly by a similar jet north of the equator that also flows to the west. On 135°W the two jets are centered at 11.5°S, 2,400 m, and 7.5°N, 2,600 m with δ^3He values ($^3He/^4He$ enrichments versus air helium) of 39% and 33%. The cores of the two jets are marked by temperature and density discontinuities like those of the deeper Benthic Front in the southwest Pacific. They both lie on the same isopycnal surface: T(Pot) = 1.67°C, S = 34.668 ‰, marking the last (?) major features of oceanic circulation to be discovered in the Pacific.

The presence of *two* ^3He deep jets, north and south of the equator, implies that they are not transient plumes from recent EPR lava flows (as had been suggested): they are actually dynamic features of the general deep circulation of the Pacific. It is interesting to observe that two such massive circulation features in the deep sea were totally unsuspected in the classical physical oceanography schemes. However, their presence reinforces the circulation picture developed by Dr. Craig, Yu-chia Chung, and Manuel E. Fiadeiro, in their 1972 discovery of the Benthic Front as a large-scale density discontinuity in the South Pacific, separating the northward-flowing Antarctic Bottom Water from the overlying southward-flowing Pacific Deep Water, both these flows are concentrated in western boundary currents. The two zonal ^3He jets feed the southward-flowing Pacific Deep Water in each hemisphere. In this schema, the classical Stommel-Arons model of 1960 is confined to the Antarctic Bottom Water flow in which water flows out of the north-flowing western boundary current, eastward and poleward. This circulation is reversed in the overlying Pacific Deep Water flowing southward on the western boundary.

The Ethiopian Hotspot and Effects of Volcanism on Rifting. Scientists in Dr. Craig's laboratory work on the African Rift Valley with emphasis on Ethiopia. The group's previous studies of ^3He in volcanic gases established the presence of a mantle plume, high in $^3He/^4He$ ratio relative to MORB helium. Drs. Paulo Scarsi and Antonio Marinello have been working in the group for the past year. They arrived from Italy with impeccable credentials—the keys and unrestricted access to some 4,000 basalt samples collected in the Ethiopian Rift by Italian scientists over the last several decades and stored away in Pisa after work on them was completed. Thus, Dr. Scarsi is studying $^3He/^4He$ in a selection of these lavas while Dr. Marinello is measuring $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ working with Dr. Macdougall. The results to date show that the plume influence is widely observed, not only in the central rift where the volcanic gases had been previously sampled, but also over the entire Afar Depression. Thus, these basalt samples allow extension of these studies over a much wider area than can be covered by volcanic gases.

Marine Biology Research Division

Dr. Robert E. Shadwick removes a blood vessel from a lobster specimen as part of his study of elastic proteins in invertebrates.

SCIENTISTS IN THE Marine Biology Research Division investigate the biochemical, physiological, and ecological characteristics of marine bacteria, animals, and plants. Their studies this year included the circulatory systems in invertebrates, the molecular genetics of pressure adaption in deep-sea bacteria, and the microbial loop in the oceanic food web dynamics.

Dr. Robert E. Shadwick explored the structure and biomechanical properties of circulatory and locomotor systems in invertebrates. During an expedition to the Azores, with a Dalhousie University colleague, very large specimens of the squid *Lologo forbesi* (up to 1 m in length and 5 kg in mass) were obtained for studies of jet swimming energetics and circulatory mechanics. These studies are the first on captive squid of such size. Dr. Shadwick will clarify how jet locomotor capabilities scale with body size in these high-powered invertebrates.

Dr. Shadwick is isolating and characterizing novel elastic proteins from invertebrate blood vessels. Early results show that cephalopods and crustaceans have vascular elastomers that are mechanically analogous to, but biochemically distinct from, the vertebrate protein elastin. Further characterization and sequencing of these proteins may clarify how elastic polymers are made in nature.

Dr. Horst Felbeck's group concentrates on the biochemistry and molecular biology of the symbiosis between chemoautotrophic bacteria and marine invertebrates. This phenomenon, found first in animals from

deep-sea hydrothermal vents, is characterized by bacteria that provide much, or all, of the nutritional needs of their hosts. Graduate student Jeffrey L. Stein has cloned, expressed, and sequenced the gene for the primary carbon dioxide fixing enzyme ribulose bisphosphate carboxylase from the symbionts of a deep sea snail. He is now characterizing this enzyme biochemically. After discovering that the bacteria in some of these symbioses use nitrate as a replacement for oxygen, graduate student Ute Hentschel is investigating the biochemical pathways used by the symbiotic system for this purpose.

The biochemical and molecular adaptations of marine organisms are being investigated in Dr. George N. Somero's laboratory. The functional and structural modifications of enzymes to extremes of hydrostatic pressure were evaluated by graduate student Elizabeth P. Dahlhoff. She found adaptations to high pressure and fine-scale differences in habitat temperature in the malate dehydrogenases (MDHs) of hydrothermal vent organisms. Laboratory scientists also sequenced cloned cDNAs for lactate dehydrogenases (LDHs) of shallow-living and deep-living fishes of the genus *Sebastolobus*. Work on multiple isoforms of malate dehydrogenase by graduate student Jen-Jen Lin showed that temperate and tropical barracuda species contain different amounts of heat-labile MDH. Differences in the thermal response between LDHs of coastal and Sea of Cortez gobies were discovered by graduate student Elizabeth L. Winter.

In a study of the adaptation of oxygen minimum zone (OMZ) fishes, graduate student Tzung-Horng Yang showed that gene expression in a normally aerobic tissue, the heart, reflects the limited oxygen availability in the OMZ. Yang developed a biochemical index allowing oxygen consumption rates to be accurately estimated from simple enzymatic analyses. Dr. Thomas J. Dietz is investigating stress protein (heat shock protein) expression in marine fishes inhabiting different thermal environments. Graduate student John O'Brien explored sulfide metabolism in symbiotic clams, which harbor sulfur bacteria. He found that their mitochondria are adapted to rapidly detoxify sulfide. Graduate student Sandor E. Kaupp is concentrating on the biochemistry of larval and juvenile fishes.

Dr. Shadwick dissecting a specimen.

Investigators in Dr. Douglas H. Bartlett's laboratory focus on the molecular genetics of pressure adaptation in deep-sea bacteria. They are examining the effects of elevated hydrostatic pressure on gene expression and enzyme function in abyssal bacteria, as well as its stressful effects on bacteria not adapted to the extremes of deep-ocean pressure. Graduate student Ellen Chi has genetically engineered the deep-sea bacterial isolate SS9 to provide for the ready identification of pressure sensing mutants. She is now isolating and characterizing the gene(s) responsible for pressure signal transduction in SS9.

Laboratory scientists have purified the enzyme malate dehydrogenase from several abyssal marine bacteria, and isolated and sequenced its gene from one isolate. In collaboration with Dr. Somero, pressure adaptation in malate dehydrogenase enzyme function is being correlated to protein sequence. In another study it was found that pressure induces the production of specific stress proteins in bacteria not adapted to high pressure. These experiments should help pinpoint key biochemical processes that are inhibited by pressure.

The ecological energetics of deep-sea benthic boundary layer communities is the focus in Dr. Kenneth L. Smith's laboratory. Long time-series measurements (>2 years) of benthic boundary layer processes continue at a 4,100 m deep station in the eastern North Pacific. Particulate organic mat-

ter flux (food supply) entering the benthic boundary layer is compared with activity rates of near-bottom animals. The animals are monitored with an acoustic array and the benthic organisms are monitored with time-lapse cameras and a sediment respirometer. There appears to be a strong summer signal in the input of particulate organic matter into the benthic boundary layer. Seasonal activity patterns of scavenging grenadier fish at this station are also evident from acoustic tagging experiments being conducted in collaboration with a University of Aberdeen scientist. The energetics and sensory biology of the deep-sea scavengers, lysianassid amphipods, are also being studied.

Dr. Victor D. Vacquier's group studies the mechanism of sperm-egg interaction during sea urchin and abalone fertilization. Abalone sperm use a protein, lysin, to make a hole in the egg envelope. The DNA coding for lysin has been sequenced from seven species of California abalone. The sequences show how gene divergence has occurred during evolution. Lysin sequences will be determined for abalone species throughout the world to clarify how the sequence has changed during the evolutionary radiation of this genus of marine mollusk. Dr. Vacquier's group also studies the proteins on the sea urchin sperm that mediate the sperm's acrosome reaction.

Dr. Walter F. Heiligenberg's group is exploring the neuronal mechanisms of sensory and motor information processing in electric fish. An endogenous oscillator in the fish's hindbrain drives the electric organ discharges at a very regular rate. In the context of social communication, however, higher brain centers can induce the same oscillator to generate specific modulations of its discharge pattern to produce corresponding modulations in the fish's electric activity. Neurophysiological and pharmacological studies demonstrate that such modulations are mediated by different neurotransmitters or different glutamate receptor subtypes. The same neuronal hardware thus can generate very different forms of behavior.

A recently acquired instrument called a laser puller has enabled investigation of neurons so small they could not be studied with previous techniques. This instrument is capable of pulling electrodes from quartz glass pipettes. Because of their hardness and extremely small tip diameter (approx. 100 nm), these electrodes can be used to record intracellularly from neurons with soma diameters of <5 μm.

Scientists in Dr. Mark E. Huntley's laboratory study plankton physiology and the ecology of planktonic communities. During two cruises near the Antarctic Peninsula, they will assess the role of zooplankton in transforming organic carbon and nitrogen, and use new biochemical techniques to measure zooplankton metabolic activity. Graduate student Walter Nordhausen continues research on the life history and physiology of the Antarctic euphausiid, *Thysanoessa macrura*. An ecosystem model was developed by graduate student Mai D. G. Lopez, Dr. Huntley, and a University of Hawaii colleague. This model shows that Antarctic birds and mammals constitute a major leak in the ocean's biological carbon pump, because they return large amounts of carbon dioxide to the atmosphere through respiration.

Dr. Farooq Azam's group investigates the role of the microbial loop in the oceanic food web dynamics and carbon cycle. They focus on the interactions of bacteria with organic particles to clarify the role of bacteria in the oceanic carbon cycle. Particles, such as marine snow, exhibit intense hydrolytic enzyme activity with the potential for rapid particle solubilization. Dr. Azam's group studied rates and mechanisms of microbial decomposition of phytodetritus in a controlled model system. Phytodetritus caused rapid (few hours) increases in bacterial growth rates and hydrolytic enzyme activities. This suggests that pelagic bacteria could respond to phytodetritus inputs by increasing the carbon flow from detritus to bacteria and thus significantly retarding vertical flux of carbon. The variability in bacteria-phytodetritus coupling appears pivotal in controlling carbon flux pathways.

The possibility of seasonal uncoupling between bacteria and phytoplankton in high latitude waters is under study in the coastal and open ocean waters off Palmer Peninsula, Antarctica. Group scientists are exploring bacteriophages and phytoplankton viruses' influence on primary and secondary productivity. A new method for measuring viral production rates in seawater shows that in the nearshore waters, bacteriophage production is on the order of 10^8-10^9 l^{-1} d^{-1}. These measurements, coupled with abundance estimates (10^9-10^{10} l^{-1}), yield viral turnover times of a few days.

Dr. Ralph A. Lewin observed that in some mineral media, calcified plaques are deposited around single-celled green algae (*Chlamydomonas* spp.). These deposits consist not of carbonate, as is usual in certain families of algae, but of phosphate, the main mineral component of vertebrate bone. It is likely that the photosynthetic activity of the cells, by absorbing CO_2, raises the local pH around the cells to a level at which the solubility product of calcium and phosphate ions exceeds the threshold for calcium phosphate precipitation. This could occur also in natural phosphate-rich waters.

Dr. Benjamin E. Volcani's group focuses on the regulation of gene expression and DNA replication by silicon in diatoms. Drs. Mark M. Hildebrand and David R. Higgins are isolating and identifying silicon-responsive genes from the marine diatom *Cylindrotheca fusiformis* by screening cDNA libraries. These libraries are generated from cultures grown in the presence of silicon and from cultures that have been depleted of silicon. A comparison of several genes that are under the control of silicon will aid in identification of the components of the genetic material that are responsible for this control. This identification could clarify the mechanism of silicon-responsive gene regulation.

Dr. Lanna Cheng worked on the production of beta-carotene from *Dunaliella*, and of *Artemia*, shrimps and purified salt.

Marine Life Research Group

Graduate student Alessandra Conversi examines water quality data presented at a poster session in the International Conference "Oceans 91."

SCIENTISTS IN THE Marine Life Research Group (MLRG) study the physics, chemistry, biology, and meteorology of the California Current and its environs. MLRG scientists, along with the other California Cooperative Oceanic Fisheries Investigations (CalCOFI) groups, (the Coastal Fisheries Resources Division of the Southwest Fisheries Science Center [NOAA/NMFS], and the Marine Resources Division, California Department of Fish and Game) continued their 41-year time series studies of the California Current ecosystem.

CalCOFI scientists embarked on quarterly hydrographic and fishery research cruises and one egg-and-larval survey cruise during the year. They also fielded a two-ship study of the relationship of ground-fish recruitment and the physical dynamics of the ocean. Because of suggestions that there might have been an incipient El Niño in the Southern Hemisphere, CalCOFI scientists were alert to the possible manifestions of a northern El Niño-like phenomenon. While some warming, well offshore and at depth, was noted in January and March 1991, the suite of 'footprints' that typify El Niño Norte had not developed in the nearshore and superficial waters by mid-1991. CalCOFI scientists agreed that large-scale episodes, such as El Niño, have long-term effects on the population size of some fishes, birds, marine mammals, and plants in and bordering the California Current. Evidence in favor of their view continues to be developed by MLRG investigators as the long time-series of CalCOFI

data continues to grow.

Dr. Edward Brinton contrasted the distribution and population structures of euphausiid zooplankton species in the California Current collected in 1990-1991 to those from the El Niño Norte period of 1983-1984. This El Niño period of low biological productivity in the California Current region was caused by a reduction in flow and in vertical mixing. An extensive spring 1983 survey showed abundances of both warm-water and cool-water species to be 60%-80% below previous spring averages, with little reproduction taking place. However, nearshore during 1990-early 1991 there was a high reproduction rate in alongshore *Nyctiphanes simplex* off southern California, responding to northward flow and chlorophyll-*a* concentrations to 8 milligrams per cubic meter. *Euphausia pacifica*, the cool-water dominant species that recovered abruptly from El Niño north of Point Conception in spring 1984, now appears to be dominated in the Southern California Bight by *N. simplex*, whose normal population center is off the Baja California coast. This appears to be a response to northward extension of the physical properties of those waters, but is not evidence of an intrusion of more tropical waters typical of El Niño episodes.

Dr. Timothy Baumgartner and Andrew Soutar, working with colleagues from Mexico, have examined the deposition of California sardine (*Sardinops sagax*) scales in the anaerobic muds of the Santa Barbara Basin to estimate the sardine population in the overlying waters during the last 1,700 years. They used sardine abundance data collected since 1930 to calibrate the number of fish scales in the mud. Thus the fish scale abundance can be used as an index of sardine biomass in the distant past. Their analysis revealed eleven major declines, and eleven subsequent recoveries, of the sardine population overlying the Santa Barbara Basin during the last 1,700 years. The average recovery period for the sardine population (defined as an increase from less than one million metric tons to over four million metric tons of biomass) occurs over a period of thirty years with the maximum recovery being seventy years. The present recovery-in-progress of the California sardine population (resulting in the reopening of a commercial fishery) may be evaluated within this context.

Graduate student Alessandra Conversi and Dr. John A. McGowan are studying the influence of sewage discharge on southern California's coastal water quality. Four water column properties (dissolved oxygen, transmissivity, temperature, and transparency) have been measured monthly from 1972-1987 near three major sewage outfalls separated in space by 30 to 200 km. Daily sewage flow information (rate of flow, suspended solids emissions) has been gathered for the same period. A time-series analysis of these data shows a complex scene highlighted by several findings: (1) all the water quality properties studied are highly variable in time, with most of the variability at annual and interannual frequencies; (2) there are no trends indicating a decline in water quality over the past 16 years; and (3) water transparency and temperature are highly correlated throughout the Southern California Bight. While total sewage flow in the bight has increased 33% and solid emissions have decreased by 42%, variability of the measured properties has not been correlated with the frequency of anthropogenic variables, but rather with the frequency of bight-wide phenomena. This suggests that bight-wide phenomena are the driving forces for the observed changes in these water-quality variables.

Dr. James J. Simpson and colleagues are combining remotely sensed data with in situ data to determine the nature of dynamical and biophysical processes in the California Current. They use a variety of statistical and mathematical methods to examine eddy dynamics in the offshore California Current, transport processes associated with upwelling filaments, and radiative transfer processes associated with variable cloud cover. They place special emphasis on the development and systematic analysis of long-term series of satellite data to determine climate-change feedback-mechanisms between ocean and atmosphere.

Dr. Loren R. Haury and a colleague continue to test the hypothesis that zooplankton patchiness, or spatial variability in numbers of zooplankters, is intensified over and around seamounts by the interaction of the plankton with the seamount and its associated currents. Their research at Fieberling Guyot (an extinct submarine volcano located 500 nautical miles west of San Diego) has shown that zooplankton abundance is reduced over the seamount when plankton migrate up in the evening from below the depth of the seamount's summit. This 'hole' in zooplankton distribution is then carried by the currents away from the seamount to cause increased patchiness in the surrounding regions. The hole is caused by the physical displacement of the zooplankton as the currents sweep them past the seamount and by intensified predation on the zooplankton by predators that live on and over the seamount.

Dr. Mark D. Ohman extended his immunochemical analyses of predation on planktonic ciliates. He and his colleagues found that first-feeding larvae of the northern anchovy capture the ciliate *Strombidium* sp. at surprisingly high rates—equivalent to their rates of capture of unarmored dinoflagellates. This implies that microbial production, when consumed by ciliates, may be an important pathway to teleost larvae and other zooplankton. In experimental work concerning ciliate growth kinetics Drs. Ohman and Richard A. Snyder found that the growth efficiency of *Strombidium* sp. has been overestimated because of the failure to take account of ciliate cell volume changes during a growth cycle.

In further ciliate studies, the researchers discovered and described a new species of ciliate designated *Strombidinopsis cheshiri*, the specific name refering to the difficulty in preserving these ciliates with all structures intact. Like Alice's cat, *S. cheshiri* tends to disappear, leaving behind only a smile of oral membranelles.

Dr. Angelo F. Carlucci's work is focused on the microheterotrophic activities in the surface microlayers or

films, and the role of microbial populations in particulate organic matter (POM) transformations in the Santa Monica Basin water column. Turnover times of amino acids were <10 hours for the coastal sites (off La Jolla) and >10 hours for the offshore sites (near San Clemente and Santa Cruz/Santa Rosa islands). Bacterial numbers and dissolved and combined free amino acids (DFAA and DCAA) were higher at the coastal sites. Enrichment factors (ratio of concentrations in surface film to 10 cm control waters) were highest at the offshore sites for bacterial numbers, DFAA, and DCAA concentrations. These observations support previous findings that surface films contain highly active microbial populations.

Drs. Mia J. Tegner and Paul K. Dayton continued their long-term studies of the ecology of kelp communities. They are focusing on how the survival of giant kelp plants, *Macrocystis pyrifera*, varies with depth and position in the Point Loma kelp forest. Storm mortality generally decreases with increasing depth. Collaboration with Dr. Richard J. Seymour defined the importance of breaking waves to mortality patterns; the inner edge of the kelp canopy appears to be defined by the magnitude of breaking waves each winter. In contrast, sea urchin-induced structural failure of holdfasts, the structures that attach the plants to the substrate, increases with increasing depth. Plants with more urchins in their holdfasts have higher storm mortality rates, and the closer the plants are to the outer edge of the forest, where urchin settlement is highest, the higher the urchin-induced cavitation rate. Thus, storm-induced and urchin-induced mortality act in opposition, and tend to equalize mortality rates across the forest. They continue to study the effects of light and temperature on kelp populations.

Dr. Thomas L. Hayward continued his studies of the physical processes that determine the growth rate of phytoplankton (primary production) in the ocean. One aspect of his research focused on the study of oligotrophic subtropical gyres. Because of their large area, these ecosystems have an important role in the oceanic carbon cycle. However, the primary production rate within these gyres is controversial because different measurement techniques yield different estimated rates. Recent observations also suggest that primary production may be significantly greater than previously thought. The determination of the correct value and the regulatory mechanism for primary production in the subtropical gyres is important because new insights into the cycling of nutrients and mixing in the upper ocean may result.

During a twenty-year study of the epipelagic ecosystem of the North Pacific subtropical gyre, MLRG scientists have seen little evidence of seasonality in biomass or production of the ecosystem's components. Recently, Dr. Elizabeth L. Venrick has reexamined the data, focusing on the phytoplanktonic component. She has developed evidence for a small, but important, seasonal cycle. This cycle has been obscured by three characteristics peculiar to the Central Pacific: (1) the significant interannual increase in phytoplankton biomass (chlorophyll) observed between 1968 and 1987, (2) the independence of shallow and deep floras, and (3) the short duration of winter mixing. When the interannual trend is removed from the data and when shallow and deep flora are evaluated independently, evidence emerges that deep winter mixing has different effects on the two floras. The abundance of shallow flora shows a rapid decline during deep mixing and recovers gradually during subsequent months. In contrast, winter mixing initiates a period of growth for the deep flora. This brief productivity period may explain the persistence of the deep species during the rest of the year when their growth rates are negligible.

In Joseph L. Reid's completed study of the top-to-bottom circulation of the South Atlantic Ocean, he found mid-depth waters do not all originate in the North Atlantic. Though such waters extend southward along the western boundary, a substantial volume of colder, less saline, and nutrient-rich water, carried through the Drake Passage by the Antarctic Circumpolar Current, turns northward through the South Atlantic. Some of these waters from the far south extend into the North Atlantic as far as 45°N at depths 2,500-3,500 m.

Marine Physical Laboratory

Dr. John A. Hildebrand works on the seismic array sensors that will be deployed from FLIP.

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

The research group led by Dr. Fred N. Spiess is working on a system for placing instruments in deep-sea drill holes, from a conventional research ship and developing (including initial application) a means for direct measurement of ocean crust displacements caused by plate-tectonic-related sea-floor motion. The wireline re-entry system design has been completed, based on a 1989-1990 successful prototype, and completion of construction is scheduled for mid-1992.

The marine geodesy program, built around MPL's precision acoustic transponder design, focused on two at-sea operations. A five-day expedition was made aboard R/V *New Horizon* to work with transponders placed in 2,000 m of water on the flat floor of Santa Cruz Basin about 210 km from San Diego. The scientists were evaluating transponder performance following modifications made in response to a previous sea test. The modified transponders performed well when interrogated from the ship. Returns at 7 km slant range were clear enough to allow round-trip travel time measurements with better than 10 μ sec accuracy (corresponding to just under 1 cm). After this success, MPL scientists joined colleagues to study how the Juan de Fuca plate is colliding with North

America, focusing on the risk of serious earthquakes in the Vancouver Island area.

A reference point was established by the scientists aboard Canadian R/V *John P. Tully* about 160 km off the coast of Vancouver Island. They used a long lived version of the transponders to establish a link between the deep sea floor and a surface float. Jet Propulsion Laboratory's Global Positioning System (GPS) satellites were used to tie the float position to the positions of GPS receivers operated by Canadian scientists at several land stations. With this sea-floor GPS/acoustic geodetic reference point established, the first long term program to use a sea-floor site to track the motion of an oceanic plate began.

Dr. Peter F. Lonsdale led a research cruise to a remote part of the southeast Pacific between Easter Island and Antarctica for geological and geophysical study of the southernmost part of the East Pacific Rise. This part of the oceanic spreading center had not been studied for twenty years, not since the advent of modern survey tools. A multibeam echo-sounder, bathymetric sidescan sonar, gravimeter, and magnetometer were used to provide a comprehensive view of the shape and structure along the 2,500 km rise crest.

Dr. Christian de Moustier participated in a joint research program, involving scientists from several institutions, to map the Knipovich Ridge system in the Norwegian-Greenland Sea. They used the Hawaii Institute of Geophysics' SeaMARC II bathymetric sidescan sonar system to record the raw sea-floor echoes. Dr. de Moustier used these data to investigate ways of improving the system's bathymetric and sea-floor acoustic imaging functions. These data have been analyzed in collaboration with Drs. Mohammad Masnadi-Shirazi and Pierre Cervenka. This resulted in the development of a new processing scheme, which has now been integrated into a redesigned real-time data acquisition system.

Dr. de Moustier also worked on acoustic backscatter measurements of the sea floor and the ocean volume, testing scattering theories with acoustic data recorded with a Sea Beam multibeam echo-sounder. A comprehensive data processing and analysis methodology has been developed from this work, and applications to data recorded with other multibeam echo-sounders have been licensed by UC San Diego.

Dr. John A. Hildebrand and collaborators Drs. Spahr C. Webb and LeRoy M. Dorman participated in the SERA (Seismic Experiments on the Rise Axis) Expedition of R/V *Thomas Washington*. A network of ocean bottom seismographs was deployed to record microseismicity on the East Pacific Rise (EPR) axis at 9°50'N. This area was considered to be potentially active because of reports of voluminous hydrothermal activity during an earlier submersible program.

A rapid OBS (Ocean Bottom Seismometer) deployment during the SERA Expedition, just one month after the first reports of activity, enabled microseismicity levels to be monitored, testing for volcanic and/or hydrothermal activity. Seven OBSs were deployed, configured as a network with 5 km spacing and spanning the EPR axis from 9°46'N to 9°51'N. Two of the instruments were examined, one on axis and an adjacent one off axis by 5 km (on axis 9°48.49'N 104°17.15'W; off axis 9°48.94'N 104°14.59'W). The seismic data were sampled at 128 Hz with 16 bits and were recorded continuously during the four day deployment.

Many waveforms were observed that followed the expected behavior for earthquakes. At one range were the regional events (distance 30-100 km) with coda of 1 minute or more and exhibiting a prominent water-propagating T-phase. The other range was local (distance 0-10 km) with a short coda and prominent impulsive P, S, and interface waves, as well as water-wave multiple reflections. The regional earthquakes were probably associated with the Clipperton transform fault—30 km north of the seismic network. The local events were associated with the EPR beneath the seismic network.

Dr. William S. Hodgkiss focuses on underwater acoustics and signal processing. The Swallow float array program continues, with the goal of taking a freely drifting array to sea to measure infrasonic acoustic ambient ocean noise in the 1-20 Hz region. Although the group of Swallow floats is freely drifting, each buoy pings every so often thus providing a localization signal that is received by the other buoys. Coherent processing of the array element outputs (beamforming) can be accomplished by knowing the locations of all elements.

Dr. Gerald L. D'Spain is working on several Swallow float experiments and the analysis of the recorded infrasonic ambient noise data. His latest experiment was carried out in the Atlantic. Dr. Jean-Marie Tran is analyzing a 1987 data set taken in the northeast Pacific. During that experiment, Dr. Hildebrand's research group deployed a 900-m vertical array from R/P FLIP. Dr. Tran has been looking at various aspects of matched field processing 200 Hz CW data.

Dr. Hodgkiss continues analysis of propagation data collected during the Downslope Conversion experiment. He focused on the physics of downslope conversion—the process by which high angle acoustic energy bouncing off the continental slope is converted into low angle energy that becomes coupled into the sound channel. For this study, a large acoustic sound source was towed back and forth across a portion of the continental slope, which had been surveyed with Sea Beam specifically for this experiment by Drs. Lonsdale and de Moustier. The Swallow float array was deployed as part of the Downslope Conversion experiment.

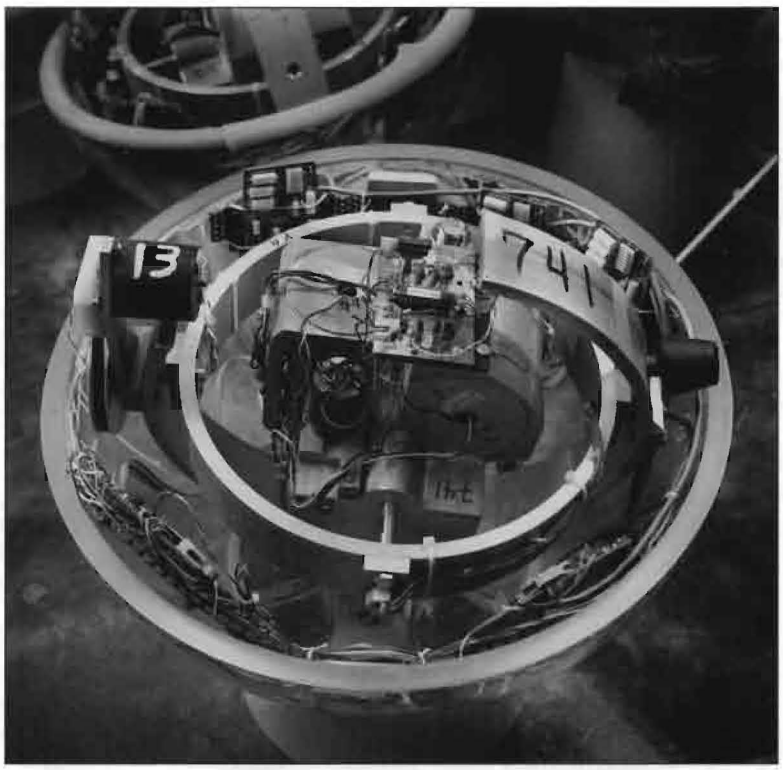
Dr. Jerome A. Smith and graduate student Gregory T. Bullard are studying the interactions of open ocean surface waves and currents. The combined effects of wind-drift and waves can cause the formation of 'Langmuir circulation' in the top layer of the ocean. Langmuir circulation is important as an efficient mechanism for mixing wind-generated momentum throughout the mixed layer; however, it has proven difficult to observe in the open ocean. Recent observations with 75-kHz and 195-kHz Doppler sonar systems have revealed definite evidence of Langmuir circulation, at scales from three times the mixed layer depth (3 x 60 m) down to the

resolution of the sonar systems (2 x 3 m). The data from one system is exciting, as it reveals an initial growth phase in the development of Langmuir circulation. These systems also measure the surface wave field. The 75-kHz system achieves 10-m resolution, and the 195-kHz system achieves 3-m resolution, corresponding to waves with 3.5 and 2 second periods respectively at the cutoff.

Exciting findings are expected as scientists expand their research to explore the evolution of surface waves and wave breaking. As a surface wave directional array, these sonar systems can distinguish between oppositely directed wave components in the open ocean. Such components may give rise to pressure fluctuations at the sea floor ('microseisms'). In addition to resolving the wave orbital velocities and the mixed layer currents, the sonar backscatter intensities clarify bubble density in the near-surface layer.

Dr. Robert Pinkel and graduate student Steven P. Anderson are searching for evidence of internal wave breaking using the profiling CTD system developed for SWAPP (a Doppler sonar system). They are also identifying the signatures of low frequency internal waves in the sea-surface Doppler sonar records. Future expeditions include a trip to the Arctic Ocean to explore the influence of open leads—cracks in the sea ice cover— on both the atmosphere and the ocean. One objective is to create a multi-beam sector-scan Doppler sonar, capable of imaging an area of the sea surface and not just along a linear acoustic beam. Researchers are developing a prototype version for this expedition. A portable data analysis system, based on an Apple MacIntosh computer system, should be capable of processing and displaying the two hundred thousand numbers per second that are expected to be produced.

Seismic sensor in a glass pressure housing.



Dr. Andrew G. Dickson's research group is developing approaches to improve at-sea measurements of the carbon dioxide system in sea water. In collaboration with Dr. Charles D. Keeling's laboratory they are preparing reference materials based either on natural sea water or on a sodium chloride solution containing sodium bicarbonate at natural levels. These reference materials are supplied to and are an integral part of the quality control of the CO_2 survey being carried out as part of the WOCE hydrographic program. The group also used one batch of these reference materials to institute a collaborative study of the extraction/coulometric technique for measuring the total dissolved inorganic carbon in sea water. This study involved fourteen European and North American laboratories.

Dr. Dickson is also refining methods for the analysis of carbon dioxide parameters in sea water. These methods include: (1) a coulometric titration method for the accurate measurement of total alkalinity in sea water, (2) the extraction/coulometric method for the measurement of total dissolved inorganic carbon, and (3) the spectrophotometric determination of the pH of sea water.

Dr. Jeffrey L. Krolik is developing and analyzing new digital signal processing techniques for underwater acoustics applications. He is concentrating on matched-field source localization in a random ocean channel, and broadband adaptive beamforming for sparse nonuniformly spaced sensor arrays. Matched-field source localization involves exploiting the complex multipath propagation conditions in the ocean channel to determine the range and depth of underwater acoustic sources with a vertical line array. Knowledge of the ocean channel is inevitably imprecise, so achieving robust localization in the face of uncertain propagation conditions is an important objective. In his effort, Dr. Krolik is developing random adiabatic normal mode models, which account for uncertainty in the ocean channel, and algorithms, which lend themselves to robust source localization.

In another project he has focused on beamforming nonuniformly spaced arrays where the average sensor spacing can be much larger than the acoustic wavelength over much of the signal band. Although most beamformers are designed to be equi-spaced, with no larger than half-wavelength inter-element spacings, in many ocean applications random fields of sensors are employed that violate these assumptions. In this work, new beamformer designs will both suppress grating plateaux interferences and maintain a fre-

USNS *Navajo* tows R/P FLIP out to sea.

quency-independent mainlobe response across very wide signal bandwidths.

Richard W. Johnson's Optical Systems Group has developed a family of automated imaging systems to assess the optical state of the atmosphere. The Whole Sky Imager (WSI) acquires images of the upper hemisphere every minute, from which automated assessment of cloud cover at one-third degree resolution may be generated. The Horizon Scanning Imager is used for determination of visibility. The WSI is providing on-line operational support at test facilities. The WSI systems have been used for three years to acquire a data base of 3 million cloud scenes.

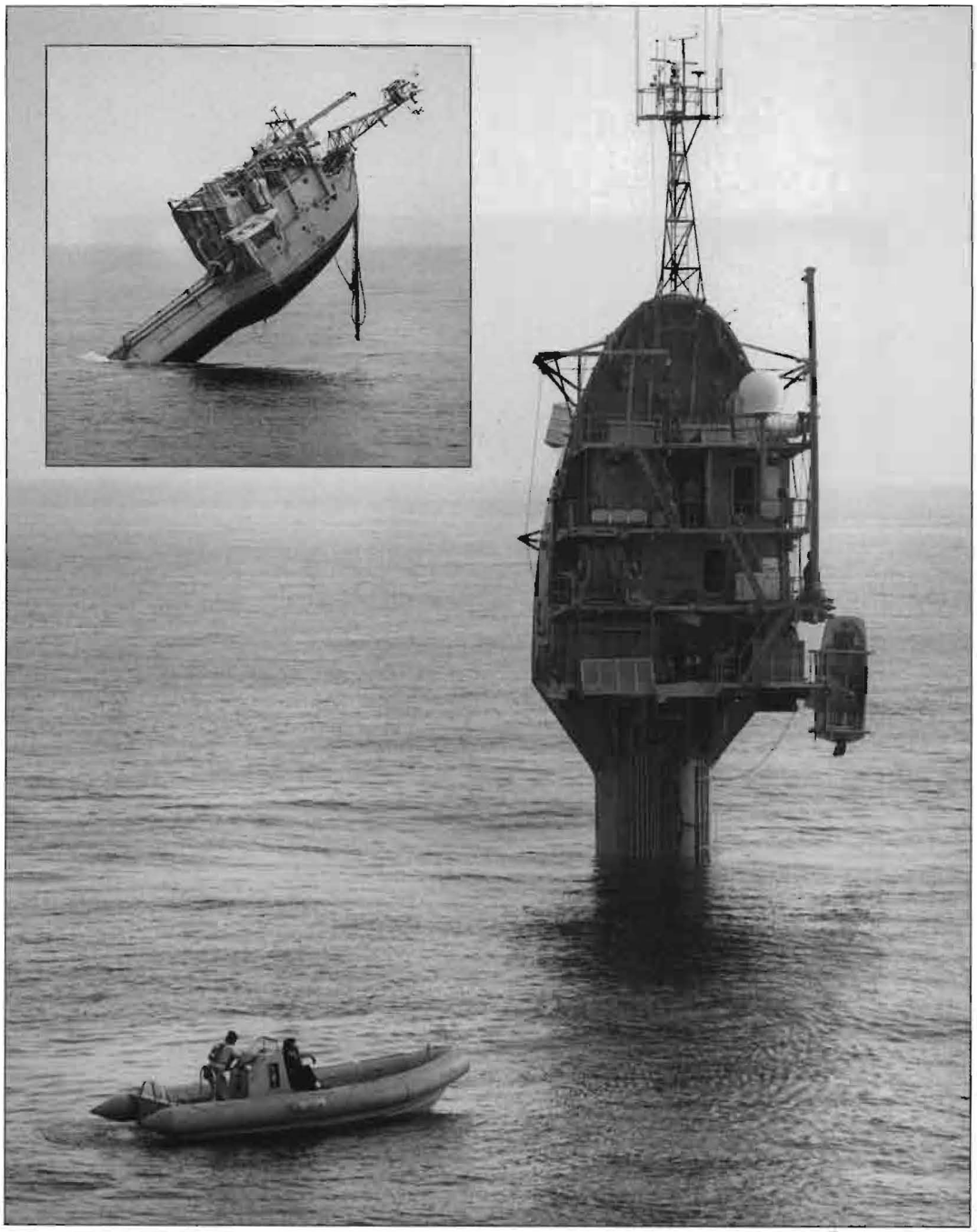
Dr. Thomas L. Koehler has improved techniques for extraction of thin cloud characteristics. Dr. Koehler and a colleague are extracting opaque and thin cloud determinations from several years of imagery data. The capabilities of the WSI are being extended into night-time, for full 24-hour operation.

Computer and software development by Dr. Eugene M. Zawadzki, and corresponding hardware development by other laboratory scientists, promise a unique capability. The system uses a slow scan CCD (charge couple device) sensor, as opposed to the CID (charge injection device) sensor used in the day WSI. Significant changes to the optical system design have been completed to enhance throughput and field of view. Like the day WSI, this new unit is being designed for full automatic data acquisition as well as automatic processing to yield cloud decision images.

The Horizon Scanning Imager is a system that can determine the horizontal line of sight visibility over extended paths. This system uses a CID camera like the day WSI. Acquiring images under automated control, it evaluates the apparent contrast of dark targets with respect to the horizon, and computes the visibility using contrast transmittance theory.

FLIP in its vertical position where it is a stable platform.

***Inset,* FLIP making the transition from its horizontal to its vertical position.**



California Space Institute

Dr. V. (Ram) Ramanathan works on the role of clouds in global climate change.

SCIENTISTS AT California Space Institute (CalSpace), established in 1979 by the UC Regents, identify and develop space sciences and technologies. The CalSpace researchers conduct and support space-related science, technological research and development, and education on the UC campuses and at the Lawrence Livermore and Los Alamos national laboratories. Director Dr. Sally K. Ride has concentrated on building the institute's in-house research and extending its role in space science education. Today the CalSpace research staff comprises about two dozen scientists who conduct research in the broad interdisciplinary fields of global change and space science. The institute is headquartered at Scripps where it has developed strong research ties with the Scripps scientific community.

Global Change Research at Scripps

Climate and global change investigations are conducted with other Scripps divisions and scientists through programs developed by Dr. David P. Rogers. CalSpace's research focuses on climate change, over periods of weeks to decades, and the complex interactions and feedbacks that link biochemical and geophysical processes in the atmosphere, oceans, and land surfaces.

Dr. Veerabhadran Ramanathan, an expert in global change studies, joined CalSpace and established the Laboratory for Cloud and Climate Research. Dr. Ramanathan is working with Dr. William D. Collins on the effects of water vapor and clouds—the dominant

regulators of the radiative heating of the planet—on climate and global warming. Although scientists have been able to identify the complex scope of cloud and water vapor feedbacks and their importance to climate change by using general circulation models (GCM), they still do not understand how these radiative effects respond to climate change. What has been needed to help clarify these uncertainties is a natural climate change experiment in a region that exhibits a strong coupling between surface temperatures and radiative fluxes.

Drs. Ramanathan and Collins have found that the tropical Pacific Ocean manifests such behavior and that near the upper range of sea surface temperatures (SSTs) the greenhouse effect increases with SST at an unstable rate, which exceeds the rate for surface heat emission. The thermodynamic response to this super greenhouse effect is the production of highly reflective cirrus clouds, which act like a thermostat shielding the ocean from solar radiation. Drs. Ramanathan and Collins have proposed that this thermodynamic regulation of radiative heating, deduced from observations of the 1987 El Niño, is the mechanism that limits SSTs to < 305 K.

Dr. Ramanathan is working with a colleague to develop tools for presenting Advanced Very High Resolution Radiometer (AVHRR) satellite images and GCM results in dynamic three-dimensional visual displays. The computer algorithm, which will aid the development of new GCM cloud parameterizations, converts visible and infrared AVHRR cloud images into three-dimensional visual models using a simple radiative transfer scheme. These graphics tools permit one to view, separately or simultaneously, the cloud, wind, precipitation, pressure, and moisture fields produced during a GCM climate experiment for any portion of a simulated atmosphere. The evolution of these fields can be seen as a movie, and it is possible to 'fly' around these model field representations and examine them from various perspectives, ranging from airplane to satellite. Preliminary results have shown some problems and possible solutions for retrieving the structure of optically thin cirrus clouds from satellite imagery.

When calculating the atmospheric energy budget using satellite data, it is necessary to identify cloudless areas in the satellite observations—not a trivial task. To resolve this problem, Dr. Collins is constructing a new algorithm for identifying clear-sky observations in Earth Radiation Budget Experiment (ERBE) scanner data. The method is based upon the different statistical relationships between albedos and outgoing infrared irradiances characteristic of clear and cloudy areas. Clear scenes are identified by growing small clusters of adjacent pixels with a Monte Carlo procedure. This method depends upon only six free parameters, yet the pixels selected are similar to the sample identified with the operational ERBE algorithm, which requires a large statistical data base. Because the distinction between the radiative correlations holds over many spatial and temporal scales, the algorithm may be readily adapted to scanner data from higher-resolution satellite instruments such as AVHRR. The method will be used to test the observation that the heating and cooling effects of equatorial clouds almost balance each other. With this method, changes in the radiative effects of clouds may be examinied using data from several generations of satellite instruments.

Dr. Anand K. Inamdar is working in the Laboratory for Cloud and Climate Research to develop detailed radiative transfer models for studying greenhouse trapping in the atmosphere. He is combining the model results with five years of climatological data to conduct sensitivity studies of water vapor feedbacks, which include the non-linear rise in the greenhouse effect at higher temperatures. Drs. Inamdar and Ramanathan also are examining the climatological data and model runs to study contrasts between El Niño and non-El Niño years to understand the development of El Niño conditions, namely the ocean surface heat balance in the tropics.

California Space Grant Consortium

CalSpace plays an important role in expanding educational opportunities for students in the interdisciplinary fields of space science and engineering, and climate and global change. In 1989 CalSpace became the designated headquarters and administrative arm of the NASA-sponsored California Space Grant Consortium. The consortium, directed by Dr. Michael J. Wiskerchen, comprises UC Berkeley, UC Los Angeles, and UC San Diego. Through its educational outreach activities the consortium develops a statewide program of space science and engineering education for kindergarten to the graduate level. This year the consortium designed undergraduate curricula and provided graduate fellowship awards. Innovative partnerships with other universities, government agencies, and aerospace corporations were fostered to provide leadership in the development and application of space resources through research, education, and public service.

CalSpace Mini-Grant Program

A major function of CalSpace is to support space sciences and global change research through the disbursement of small research funds to individual scientists. The CalSpace mini-grant program promotes space-related research by awarding one-year grants for studies in the fields of space science and engineering, astronomy and astrophysics, satellite remote sensing, and global change. The program, open to all researchers in the UC system, is designed to provide seed money to explore and develop innovative areas of space-related research. Particularly encouraged are proposals that support graduate students and postgraduate researchers. During the 1990-1991 fiscal year, the CalSpace mini-grant program attracted nearly one hundred proposals covering a wide range of topics, and CalSpace awarded $718,426 to 48 investigators. Funded research varied from infrared astronomy detector development to the study of Antarctic clouds and radiation.

Institute of Geophysics and Planetary Physics

The 732-m long laser strainmeter at the Cecil and Ida Green Piñon Flat Observatory.

THE SAN DIEGO BRANCH of the University of California systemwide Institute of Geophysics and Planetary Physics (IGPP) is located at Scripps and is strongly linked to Scripps through joint faculty appointments, research interests, and shared facilities. Other IGPP branches are located at the Los Angeles and Riverside campuses and at the Los Alamos and Lawrence Livermore national laboratories. Research at IGPP spans fields from the development and operation of global seismic networks to theoretical seismology and theoretical geophysics. This report focuses on global seismology—data collection and its analysis.

Global Seismology: Building Models of the Earth's Interior

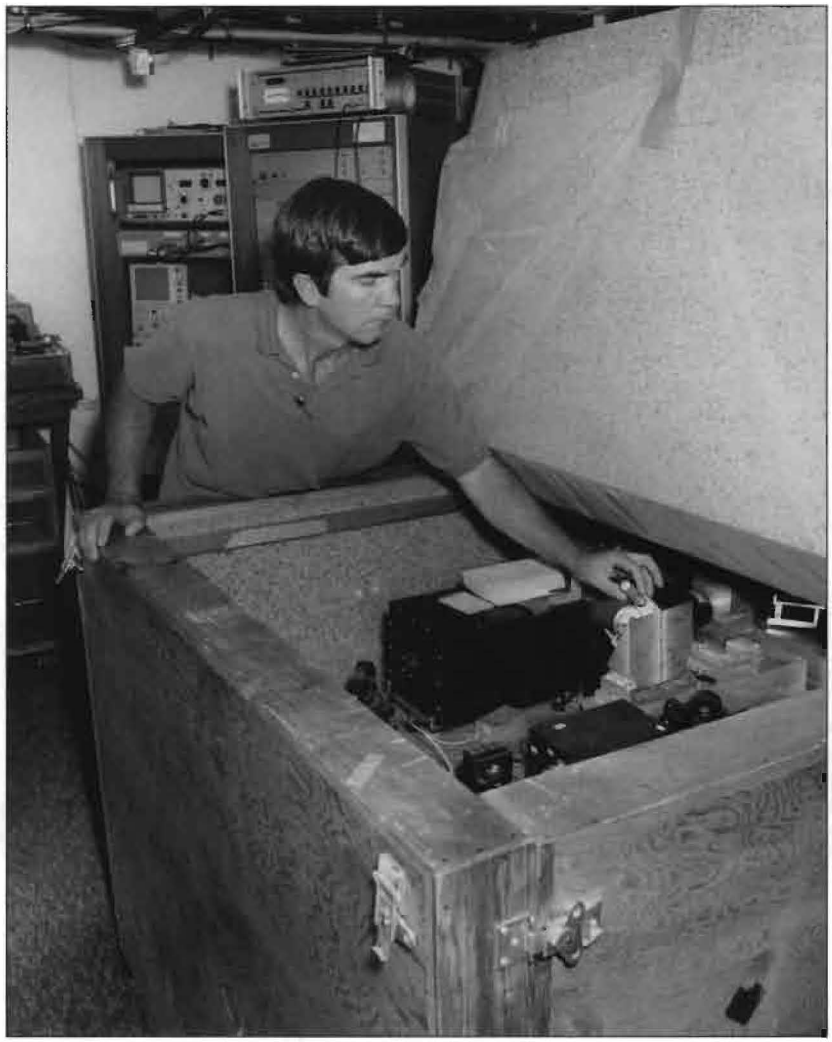
It may seem strange that an oceanographic institution is renowned for its contributions in global seismology. One could argue that most of the research to date has had little impact on our understanding of the oceans and the ocean floor. Until the 1980s global seismologists did not have sufficient high-quality data to address anything but the spherically averaged structure of the Earth with any degree of confidence.

With the advent of global digital seismic arrays (which the institution has played a major role in developing), global seismologists can now image the large-scale three-dimensional structure of the mantle both under continents and oceans. Such images provide a basis for interpreting many kinds of geophysical, geochemical, and

geological information. Early models are already used in geochemical isotope interpretations (some might say overused).

Scripps has been on the forefront of research into the Earth's three-dimensional structure. In the late 1970s, a theoretical framework for interpreting the long-period spectra of recordings of large earthquakes in terms of large-scale structure was formulated here. In the early 1980s, high-quality digital data (collected by Scripps seismologists) allowed scientists to apply this new theory to model the largest-scale structure of the Earth. More detailed models followed from several institutions, based on short-period travel-time data as well as the long-period digital data. These models show significant variability in all but the largest-scale features, and there are legitimate questions as to what features are truly resolved by the data. This, of course, has not stopped other disciplines from using the seismic models in their interpretations and clearly points out the need for reliable images.

Robert C. McDermott checks the laser strainmeter optics at Piñon Flat Observatory.



Travel-time data provide the most detailed picture of global structure though the existing compilations are extremely noisy. This has prompted IGPP scientists to use the digital arrays to construct new homogeneous catalogs of high quality travel-time measurements. These data are beginning to reveal a mantle that has a high level of heterogeneity at its base as well as its top. Until now, many scientists have assumed that the lower mantle is relatively homogeneous and that seismic phases, which traverse both lower and upper mantles may acquire most of their anomalous properties in the upper mantle. This assumption is incorrect and has led to the mapping of lower mantle structure into upper mantle structure.

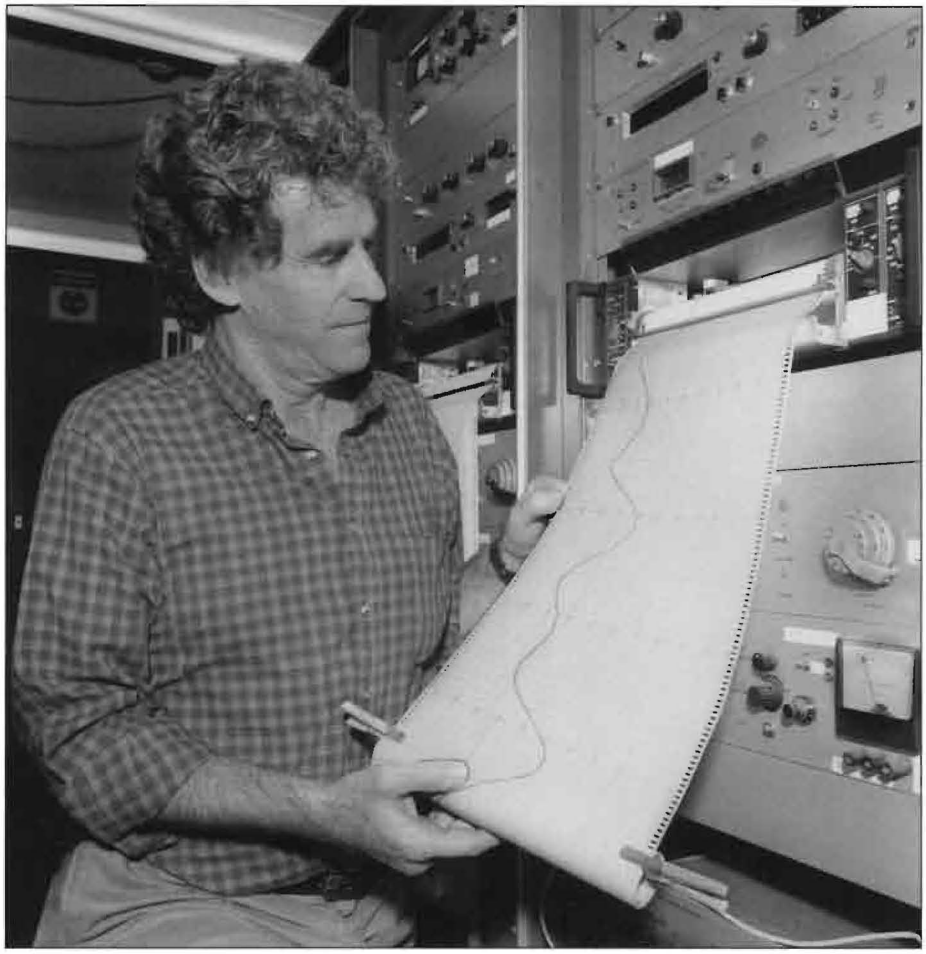
The tectosphere hypothesis put forward in the late 1970s, based on seismic phases that cross the whole mantle, is a good example. This theory argued that old oceans were significantly slower in seismic velocity than continental cratons and required chemical differences between the two regions to great depth. The data now verify that old oceans are, on average, about as fast as the continental cratons, as predicted by the standard thermal models. This example illustrates the need for a whole earth approach to the interpretation of seismic data.

Slab penetration into the lower mantle and the question of mass transfer between the upper and lower mantles is another example. The data used to infer deep slab structure are sensitive to structure throughout the mantle. The controversy surrounding the penetration question is unlikely to be resolved until models of complete mantle structure are available.

The modern digital data are also amenable to computer-based array processing techniques, which can enhance images of global-scale reflectors. IGPP scientists have just started this kind of research, but already have found evidence of a globally coherent reflector at a depth of about 520 km (between the well-imaged 400 and 670 km discontinuities).

Global Seismic Networks

There is a substantial infrastructure supporting research in global seismology at IGPP. The IDA (International Deployment of Accelerometers) seismographic network comprises 25 stations located in 15 countries on all continents including Antarctica. The network is presently being expanded through installations in the Soviet Union and China. Started in 1975, the network is now being upgraded to include broadband, three-component seismometers with high dynamic range. The current five year plan for the IDA network expansion, accepted



Dr. Jonathan Berger checks the field records at the IDA network station.

by the IRIS (Incorporated Research Institutions for Seismology) consortium, calls for 25 new stations.

IDA program scientists have pioneered the use of satellite telemetry in the near real-time collection of data; six stations are presently received over satellite channels and this number will more than double by the end of next year. Program scientists developed a satellite base data collection system using the international IBS service of INTELSAT. Available globally, this system provides cost effective use of standard satellite channels in a time-share mode to collect data from widely separated stations. Currently such a system is in operation at IGPP and records data from three stations located in China. Additionally, dedicated satellite circuits are in operation between computer facilities in China, in the USSR, and at IGPP.

Some of the IDA stations may be equipped with Global Positioning System (GPS) receivers for geodetic measurements and orbit determinations, environmental monitors, and duplex satellite communications channels. Currently the daily flow of data from the IDA network amounts to approximately 100 Mbytes/day. These data must be processed and archived in a manner convenient for recovery and further analysis. IGPP scientists have implemented a data archive using a new mass store system with a capacity of 330 Gbytes. The system includes over 7 Gbytes of magnetic (disks), 30 Gbytes of erasable optical, and 300 Gbytes of write-once-read-many optical storage.

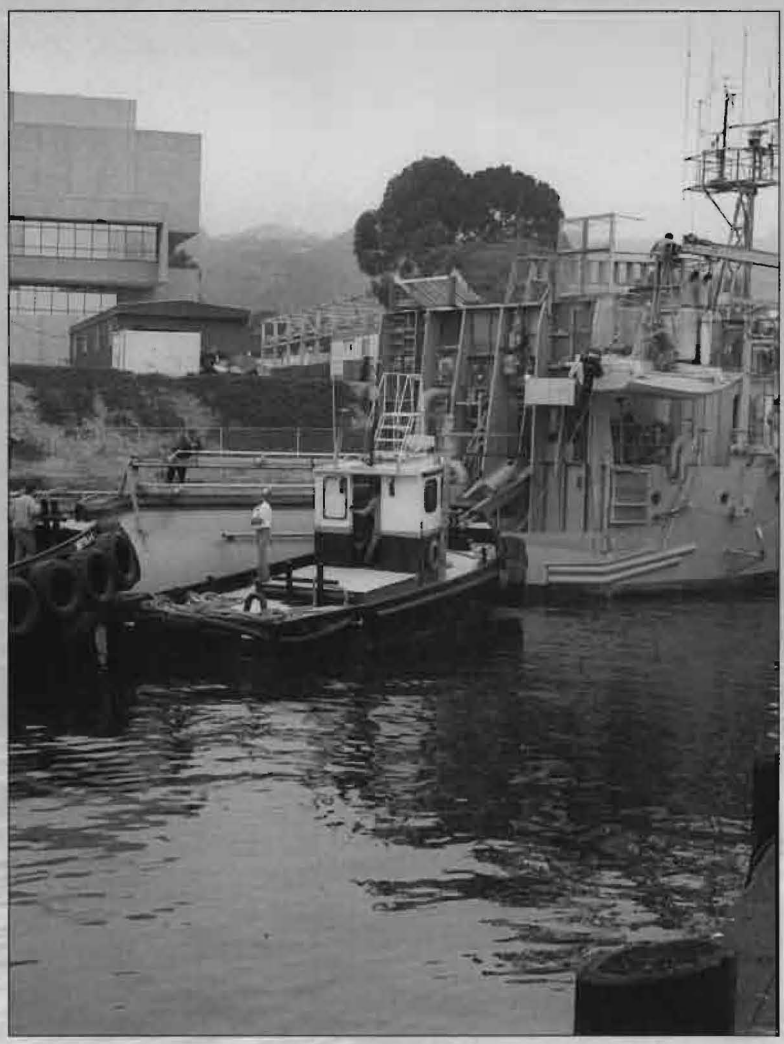
The rapid growth of all IGPP research programs over the past few years has necessitated an expansion of laboratory and office space. An extension to the present IGPP building is being designed. The expansion, made possible by contributions to the Cecil and Ida Green Foundation for the Earth Sciences, will be completed by 1993. The new portion will house 27 new faculty and research staff, 30 graduate students, and 12 post doctoral students and will include several large laboratories and a classroom.

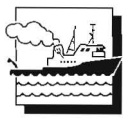
Institute of Marine Resources

This Scripps building houses the Sea Grant Program.

THE UNIVERSITYWIDE Institute of Marine Resources (IMR), headed by Acting Director William H. Fenical, oversees research programs at Scripps and UC Davis. IMR also administers the California Sea Grant College—largest of the 30 state programs that make up the National Sea Grant College Program. California Sea Grant, directed by Dr. James J. Sullivan, is also headquartered at Scripps.

Scientists supported by California Sea Grant conducted research, extension, and education activities at eight of the nine campuses of the University of California and at various campuses in the California state university system. Because Sea Grant's mandate is to promote wise use of marine resources, the research projects it supports are application-oriented. Projects funded at Scripps fall into the areas of ocean engineering, coastal resources, fisheries, and new marine products. Each involves support of one or two graduate students.





Research Fleet

One of the main tools in the study of the ocean is our oceanographic fleet, which is made up of four research vessels and two platforms. Our fleet traveled more than 76,568 nautical miles in fiscal 1990-1991 and operated at total of 613 days. The following charts briefly describe the areas of operations, work performed, and ports of call of this past years expeditions.

R/V *Robert Gordon Sproul*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	MASTER
7/2-7/3/90		Off San Diego	NSF short course	San Diego	C. Nelson (USD)	L. Zimm
7/16-7/19/90		Santa Barbara Basin	Clam collection	San Diego	H. Felbeck	L. Zimm
7/25-7/29/90		Southwest of San Diego	Equipment testing	San Diego	D. Lal	L. Zimm
8/20-8/23/90		San Clemente Basin and Patton Escarpment	Benthic biology	San Diego	A. Yayanos	L. Zimm
8/27-8/29/90	CaBS 13	Santa Monica Basin	Mooring recovery	San Diego	W. Peterson (UW)	L. Zimm
8/29-9/4/90		Santa Monica Basin	Clam collection and hydrocasts	San Diego	D. Smith	L. Zimm
9/5-9/6/90		Off San Diego	Equipment tests and diving	San Diego	K. Smith	L. Zimm
9/10-9/17/90		Transit to Astoria	Transit	Astoria		L. Zimm
9/20-10/25/90		Columbia River	Estuarine studies on the Columbia River	Astoria	C. Simenstad (UW)	L. Zimm
10/25-10/29/90		Transit to Port Hueneme	Transit	Port Hueneme		L. Zimm
10/29-10/30/90		El Segundo sewer outfall	Clam collection	San Diego	J. O'Brien	L. Zimm
11/16-11/21/90		Continental borderlands	Student cruise	San Diego	K. Smith	C. Curl
11/30-12/3/90		Southern California coast	Tracer experiment	San Diego	D. Lal	C. Curl
12/7-12/8/90		Off San Diego coast	Testing ALACE drifters	San Diego	L. Regier	C. Curl
12/11/90		Off San Diego coast	Testing drifter	San Diego	P. Niiler	C. Curl
1/23-1/25/91		San Clemente Basin	Equipment testing	San Diego	C. Reimers	L. Zimm
2/5-2/7/91		Southern California coast	Barophilic bacteria study	San Diego	A. Yayanos	L. Zimm
2/19-2/20/91		SW of San Clemente Island	Testing drifter	San Diego	P. Niiler	L. Zimm
3/1/91		Off San Diego coast	Testing drifter	San Diego	J. Paduan	L. Zimm
3/6-3/8/91		Hyperion sewage outfall	Clam collection	San Diego	D. Wilmot	L. Zimm
3/11-3/25/91		Guadalupe Island	Geological studies	San Diego	J. Hildebrand J. M. Stevenson	L. Zimm
4/17-4/18/91		Off San Diego coast	Testing ALACE drifters	San Diego	J. Sherman	L. Zimm
4/23-4/25/91		Off San Diego coast	Barophilic bacteria study	San Diego	A. Yayanos	L. Zimm
5/18/91		Off San Diego coast	Student cruise	San Diego	R. Rosenblatt	L. Zimm
6/12-6/15/91		103 km west of San Diego	Drifter tests and CTD work	San Diego	P. Niiler	R. Price
6/18-6/19/91		San Diego Trough	Install tiltmeters	San Diego	S. Constable	L. Zimm
6/25/91		Off San Diego coast	NSF short course	San Diego	S. Lowery (USD)	L. Zimm
6/26/91		Off San Diego coast	NSF short course	San Diego	S. Sturz (USD)	L. Zimm

TOTAL DISTANCE TRAVELED: 9,189.50 nautical miles **OPERATING DAYS:** 121

R/V *New Horizon*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
7/7-7/14/90	CaBS-12 Leg 1	California basins	Hydrocast and sampling	San Diego	A. Carlucci	E. Buck
7/14-7/19/90	CaBS-12 Leg 2	California basins	Hydrocast and sampling	San Pedro	N. Kachel (UW)	E. Buck
7/25-8/9/90	CalCOFI 9008	California coast	California Current studies	San Diego	M. Mullin	E. Buck
8/23-8/28/90		West of San Diego	Visibility measurements	San Diego	K. Voss (U. of Miami)	E. Buck
8/31-9/8/90		Santa Cruz Basin	GPS and acoustic studies	San Diego	F. Spiess	E. Buck
9/12-9/26/90		SW of Los Angeles	Microbiological samples	San Diego	J. Fuhrman (USC)	R. Haines
9/29-10/17/90		West of San Diego	Biological samples	San Diego	D. Wiesenburg (T A&M U)	R. Haines
10/21-10/28/90	Pulse V	Off Point Conception	Benthic biology	San Diego	K. Smith	E. Buck
11/5-11/20/90	CalCOFI 9011	California coast	California Current studies	San Diego	E. Venrick	E. Buck
11/17/90-1/25/91	Overhaul					
2/18-2/27/91	Pulse VI	Southern California	Benthic biology	San Diego	K. Smith	E. Buck
3/4-3/28/91		Fieberling Guyot	Physical oceanography	San Diego	J. Toole (WHOI)	E. Buck
4/24-5/11/91	Fieberling I	Fieberling Guyot	Physical oceanography	San Diego	G. Roden (UW)	E. Buck
5/15-5/24/91	Fieberling II	Fieberling Guyot	Benthic biology	San Diego	K. Smith	E. Buck
6/03-6/16/91		California coast	Coring, hydrocasts, free vehicle deployment	San Diego	C. Reimers	E. Buck
6/19-6/28/91	Pulse VII	Fieberling Guyot	Benthic biology	San Diego	K. Smith	E. Buck

TOTAL DISTANCE TRAVELED: 14,823.50 nautical miles **OPERATING DAYS:** 189

R/V *Thomas Washington*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
6/29-7/9/90	Plume VIII	Transit	Transit to Manzanillo	Manzanillo		T. Desjardins
7/11-7/26/90	Plume IX	Off NW coast of Mexico	Sea Beam, seismics and magnetics	San Diego	P. Lonsdale	A. Arsenault
8/19-8/23/90		Transit to Astoria	Transit	Astoria		A. Arsenault
8/24-9/4/90		322 km off Newport, OR	Rock drill tests	Astoria	P. Johnson (UW)	A. Arsenault
9/4-9/8/90		Transit	Transit to San Diego	San Diego		A. Arsenault
9/12-9/19/90	TOPO 90 I	Fieberling Guyot	Set and recover moorings	San Diego	K. Brink (WHOI)	T. Desjardins
9/22-10/1/90	TOPO 90 II	Fieberling Guyot	Deploy moorings	San Diego	C. Eriksen (UW)	T. Desjardins
11/8-11/11/90		Westfall Seamount and Guadalupe Fracture Zone	Student cruise	San Diego	P. Lonsdale	T. Desjardins
11/15-12/15/90	Rapa I	East Pacific Rise	Sea Beam, SeaMARC II	Manzanillo	K. Macdonald (UCSB)	T. Desjardins
12/18/90-1/5/91	Rapa II	East Pacific Rise	Transit, Sea Beam and SeaMARC II	Easter Island	D. Forsyth (Brown)	A. Arsenault
1/7-2/18/91	Rapa III	So. East Pacific Rise	Sea Beam and SeaMARC II	Easter Island (Intermediate stop in Easter Island)	P. Lonsdale	A. Arsenault
2/20-3/8/91	Rapa IV	Transit to San Diego	Transit and Sea Beam survey	San Diego	D. Scheirer (UCSB)	A. Arsenault
3/28-5/2/91	TERA I	Garret Fracture Zone	Seismics, OBSs	Manzanillo	J. Orcutt	T. Desjardins
5/5-5/21/91	SERA I	East Pacific Rise	Seismics, gravity, and OBS studies	San Diego	J. Hildebrand	T. Desjardins
5/31-7/11/91	TUNES I	135°W	WOCE P17C	San Diego (Intermediate stop in Pt. San Luis Obispo)	M. Tsuchiya	T. Desjardins

TOTAL DISTANCE TRAVELED: 52,275.40 nautical miles **OPERATING DAYS:** 284

R/V *Melville*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
NONE						

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

R/P FLIP

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	O I C*
7/27-8/10/90		32°50'N, 120°50'W	Optical propagation	San Diego	R. Weller (WHOI)	*D. Efird
10/30/90		32°40'N, 117°30'W	FLIP dynamics test	San Diego	F. Fisher	*D. Efrid
2/4-2/7/91		30°N, 120°W	FLIP motion studies	San Diego	F. Fisher	*D. Efrid

TOTAL DISTANCE TOWED: 280 nautical miles **OPERATING DAYS:** 19 *OFFICER-IN-CHARGE OF FLOATING PLATFORM

R/P ORB

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	O I C*
NONE						

TOTAL DISTANCE TOWED: 0 nautical miles **OPERATING DAYS:** 0 *OFFICER-IN-CHARGE OF FLOATING PLATFORM

Research Vessel Statistics

	MELVILLE	*NEW HORIZON*	*ROBERT GORDON SPROUL*	*THOMAS WASHINGTON*	FLIP	ORB
TYPE	Oceanographic research	Oceanographic research	Offshore supply	Oceanographic research	FLoating Instrument Platform	Oceanographic Research Buoy
YEAR BUILT	1969	1978	1981	1965	1962	1968
YEAR ACQUIRED BY SCRIPPS	1969	1978	1984	1965	1962	1968
OWNER	U.S. Navy	University of California	University of California	U.S. Navy	U.S. Navy	U.S. Navy
LENGTH	85.04 m	51.8 m	38.1 m	63.65 m	108.2 m	21.0 m
BEAM	14.02 m	10.97 m	9.75 m	12.1 m	6.0 m	13.7 m
DRAFT	5.02 m	3.85 m	2.59 m	4.77 m	3.4/91.4 m	fwd 1.5 m aft 1.6 m
DISPLACEMENT FULL (metric tons)	3,005.32	1,097.28	532.38	1,383.79	711.2	335.28
CRUISING SPEED (knots)	12	10	9.5	10	varies*	varies*
RANGE (nautical miles)	14,100	7,500	3,800	8,200	varies*	varies*
CREW	23	12	5	23	5	5
SCIENTIFIC PARTY	35	17	14	22	11	11

FISCAL 1990-1991 TOTAL NAUTICAL MILES TRAVELED: 76,568.4 **TOTAL OPERATING DAYS:** 613 *Depends on towing vessel

(Left to Right), **Drs. Angelo Carlucci and Farooq Azam listen to graduate student Gabriela M. Tobal present a paper in their marine microbial ecology class.**

Curricular Programs

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

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

Applied Ocean Sciences

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

Biological Oceanography

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

Geochemistry and Marine Chemistry

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

Geological Sciences

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

Geophysics

This curriculum is designed to educate the physicist (theoretician or experimentalist) about the sea, the solid earth on which the waters move, and the atmosphere with which the sea interacts. Students gain understanding of the nature of the earth while they master new field, laboratory, and mathematical techniques.

Marine Biology

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

Physical Oceanography

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

Student Enrollment

In the fall of 1990, 28 new students were admitted to graduate study. Of these, 7 were in marine biology, 3 in geological sciences, 5 in geochemistry and marine chemistry, 6 in geophysics, 3 in physical oceanography, 3 in applied ocean sciences, and 1 in biological oceanography. Enrollment at the beginning of the academic year was 183. UC San Diego awarded 26 Doctor of Philosophy degrees and 7 Master of Science degrees to the students listed in this section.

Graduate Students and Degree Recipients

Doctor of Philosophy Degrees Awarded, with Titles of Dissertations

Earth Sciences

Donald G. Albert, "The Attenuation of Outdoor Sound Propagation Levels by a Snow Cover."

Richard C. Aster, "Crustal Shear Wave Anisotropy and Near-Surface Attenuation in the Anza Seismic Gap."

Rainer Hollerbach, "Alpha-Effect Dynamos and Taylor's Constraint in the Asymptotic Limit of Small Viscosity."

Nancy E. King, "Multiple Taper Spectral Analysis of Earth Rotation Data."

Kenneth H. Rubin, "Timing, Extent and Sources of Marine Volcanism through U-Series Disequilibrium."

Michael R. Wing, "Characterization of Polycyclic Aromatic Hydrocarbons in Geochemical Materials by Two-Step Laser Mass Spectrometry."

Guoping Wu, "The Planktonic Isotopic Records and Carbonate Dissolution Cycles in the Western Equatorial Pacific for the Last Half Million Years."

Marine Biology

Louis H. Bookbinder, "Sea Urchin Sperm Adenylate Cyclase."

Sharon H. Kramer, "Habitat Specificity and Ontogenetic Movements of Juvenile California Halibut, *Paralichthys Californicus*, and Other Flatfishes in Shallow Waters of Southern California."

Mai D. G. Lopez, "Interaction between Development and Mortality Rates in Copepods."

Paul F. Sykes, "Physiological-Ecology and Chemical-Ecology of Copepod-Dinoflagellate Interactions."

Oceanography

Sabine E. Apitz, "The Lithification of Ridge Flank Basal Carbonates: Characterization and Implications for Sr/Ca and Mg/Ca in Marine Chalks and Limestones."

Joan M. Bernhard, "The Ecology of Benthic Foraminiferida with Emphasis on their Distribution in Anoxic Sediments."

Frederick M. Bingham, "Circulation and Water Mass Transformation as Related to the Formation of Subtropical Mode Water in the North Pacific."

Steven C. Bobzin, "Chemistry and Chemical Ecology of Marine Sponges of the Order Dendroceratida."

Gerald L. D'Spain, "Energetics of the Ocean's Infrasonic Sound Field."

Kenneth A. Farley, "Rare Gas and Radiogenic Isotopes in South Pacific Ocean Island Basalts."

Thomas H. C. Herbers, "Array Measurements of Surface Gravity Waves."

David B. King, "Studies in Oscillatory Flow Bedload Sediment Transport."

William C. O'Reilly, "Modeling Surface Gravity Waves in the Southern California Bight."

Timothy J. Ragen, "The Estimation of Theoretical Population Levels for Natural Populations."

Forrest E. Sloan, "Investigations into the Effects of Long-Term Seawater Exposure on Graphite/Epoxy Composite Materials."

Anne A. Sturz, "Experimental Hydrothermal Reactions between Hemipelagic Sediments and Seawater."

W. Waldo Wakefield II, "Patterns in the Distribution of Demersal Fishes on Upper Continental Slope off Central California with Studies on the Role of Ontogenetic Vertical Migration in Particle Flux."

Richard J. Williams, "The Hydraulics of Layered and Stratified Fluids Flowing through a Contraction."

Meixun Zhao, "Protein and Extraterrestrial Amino Acids in Cretaceous-Tertiary Boundary Sediments."

Master of Science Degrees

Earth Sciences

Yvette J. Liebesman

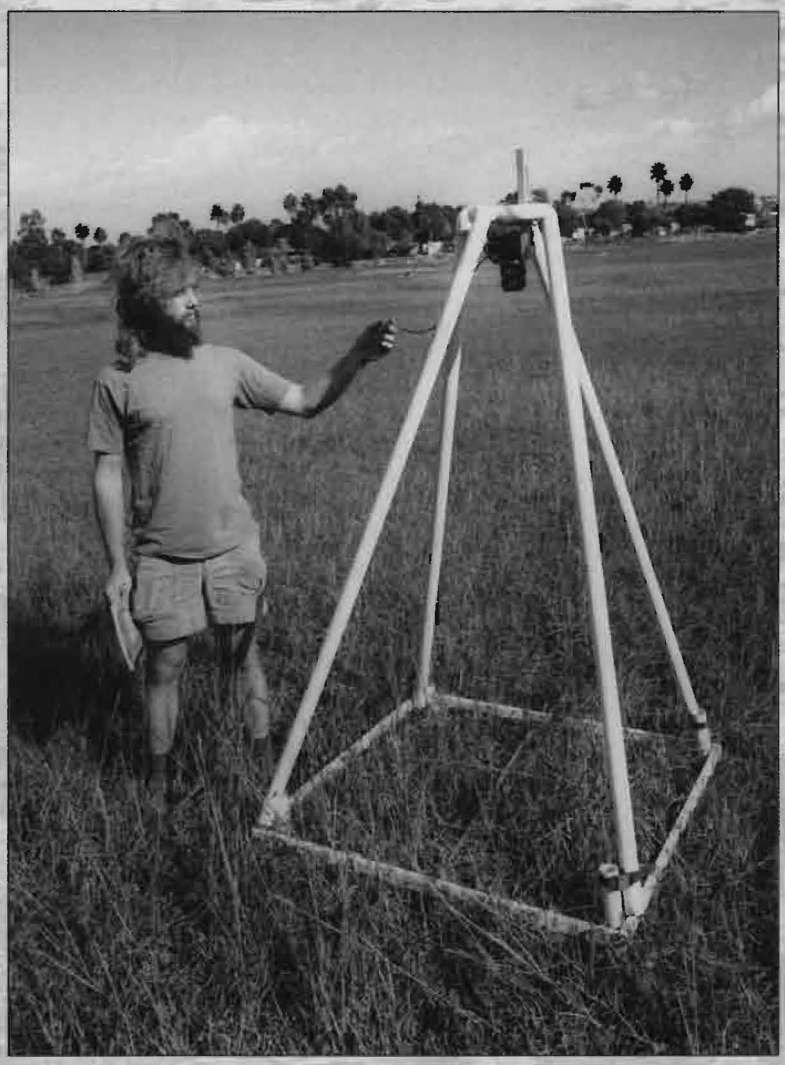
Marine Biology

Kristin R. Carner

Oceanography

Randall E. Bolick
Timothy C. Gallaudet
Andrew W. Palowitch
Minkyu Park
Robert C. Sparrock

Scott Eliason prepares to photograph marsh vegetation in a 1-m x 1-m square plot using his custom-built "quadrapod," which provides highly consistent long-term photo monitoring of the Kendall-Frost Mission Bay Marsh Reserve.



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

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

Each year one of these facilities or collections is described in photos. This year the Kendall-Frost Mission Bay Marsh Reserve is featured throughout this section.

Shore Facilities

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

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

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

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

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

In background Eliason paddles across the Kendall-Frost preserve.

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

On an average 130 faculty, staff, and students participate in this program yearly. An average of 3,600 dives has led to an accumulation of nearly 200,000 dives over a 30-year period throughout the world's many aquatic environments.

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

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

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

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

Kendall-Frost Mission Bay Marsh Reserve (Mission Bay, San Diego) Approximately 50 acres of Mission Bay marshland (16 acres university owned) constitute a marsh preserve and wildlife refuge designated for

Insets, (both pages). **Reserve manager Isabelle Kay at work on marsh projects that include the estimation of numbers of migratory birds visiting the marsh each fall and inspection of a nudibranch egg-mass.**

teaching and research. The reserve is the last fragment of the once extensive Mission Bay salt marsh. This property is one of 27 natural reserves used for teaching and research in the University of California Natural Reserve System. A small laboratory is located on the preserve. For more information write to **University of California, San Diego, Reserve Manager, UC San Diego Natural Reserve System, Scripps Institution of Oceanography 0201, 9500 Gilman Drive, La Jolla, California 92093-0201.**

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

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

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

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

Radio Station WWD
Owned and operated by Scripps and licensed to the National Marine Fisheries Service (NMFS), station WWD provides worldwide communications services to Scripps, NMFS, and other gov-

Above. **Eliason checks experimental apparatus used in a study of marsh invertebrates in the preserve.**

Left. **Kay examines the erosional process at the lower edge of the marsh.**

ernmental and university ships. Western Union (TWX-Telex), TELEFAX, and Telemail services are available for the San Diego campus. WWD has computerized its radio and TWX-Telex for local users.

Scripps Coastal Reserve
The reserve area is situated just north of La Jolla, where a small hooked bay opens to the northwest. The shelf area within the bay is cut by two branches of the Scripps submarine canyon, extending to within 300 m of the low-tide shoreline.

This area is collectively called the Knoll and consists of two coastal canyons, the knoll between the canyons, and 106-m-high, steep sea cliffs. Numerous archaeological sites are located in this region.

The shoreline area consists of intertidal rocky and beach environments; the underwater area contains various subtidal marine habitats including the canyon and a 320-m pier. The area is adjacent to the San Diego-La Jolla Ecological Reserve of the California Department of Fish and Game.

Scripps Library
With outstanding collections in oceanography, marine biology, and marine technology, in addition to extensive resources in atmospheric sciences, ecology, fisheries, geology, geophysics, and zoology, the Scripps library is one of the largest marine science libraries in the world. The library currently receives more than 3,800 serial titles and has more than 225,000 volumes, including an extensive collection of technical reports and a rare book collection featuring accounts and journals of famous voyages of scientific discovery. A large map collection contains bathymetric, geologic, and topographic maps and charts of world areas and oceans.

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

Scripps Satellite Oceanography Center (SSOC)
This facility enables oceanographers to receive and process satellite imagery. Data transmitted in real time by the NOAA polar orbiting satellites are received by the 5-m tracking antenna. In addition to real-time coverage, retrospective archives of worldwide data are also available. The most commonly used sensors include the Advanced Very High Resolution Radiometer (AVHRR) and Coastal Zone Color Scanner (CZCS), which provide information in the infrared and visible portions of the spectrum. During early 1990 the old Scientific Atlanta orbital tracker was replaced and other antenna upgrades were made. A new UNIX-based capture system, consisting of an HP 9000/370 work station, new bit and frame synchronizer was installed. Data are now archived on magneto-optical disc and/or DAT

Reserve caretakers at work.

tape. Capture is fully automated and different S or L band data passes can be intermixed in the collection process.

A new user's center was opened and a UNIX-based image analysis work station is available for general image processing. This system consists of a dedicated HP 9000/370 work station with 16 Mbytes of RAM and 1 Gbyte of magnetic disc. The 660 Mbyte multiple read, multiple write magneto-optical discs, DOS-Partition, HP 7980 1600/6250 streaming tape drive, 24-bit plane image display, and a precision camera are interfaced to this user machine for executing digital image analysis applications. A separate terminal room is available for software development by center users.

A new HP 9000/380 work station with magneto-optical autochanger capability (presently 28 Gbytes and expanding) has been installed for archiving all AVHRR data taken by SSOC since 1979. An on-line digital browse and automatic data ordering system using X Window protocols is being developed for use with this system. When completed, this system will be interfaced to national networks so the SSOC data base can be accessed via the network by non-local users.

Current applications include near-real-time support of research vessels and aircraft with remotely sensed images to detect phenomena of interest for their in situ observation programs. Other activities include determination of sea-surface temperature anomalies, retrospective analysis of image data sets in relation to physical and biological oceanography studies, real-time support of fishing fleet operations and cloud/radiation studies to investigate global change processes. It is anticipated that GEOSAT altimeter and GOES data also will be processed on the new systems. Four-day courses are frequently taught to give potential users an overview of the available tools and hands-on experience. Advanced programing and digital image analysis courses also are offered on a periodic basis.

Seawater System

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

Shipboard Technical Support

Shipboard Technical Support is an amalgamation of several groups that serve both Scripps and the oceanographic community at large. The group provides technical and data-collection services aboard Scripps's research vessels, supplying and main-

taining shipboard scientific facilities (computers and geological, biological, physical, and chemical data-acquisition systems); logistic support for these facilities; and postcruise data processing, distribution, and archiving. Shipboard Technical Support also furnishes data collection equipment and highly trained technicians for University National Oceanographic Laboratory System (UNOLS) ships and international programs.

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

The Shipboard Computer Group is composed of programers and engineers who support VAX/UNIX computers ashore and at sea through programing, interface design, and maintenance. A shore-based VAX 750, available for use by the Scripps community, supports the VAX 730s on the ships. These computers are installed permanently on R/V *Thomas Washington* and R/V *Melville*, and they are interfaced to navigational and scientific instruments, including the R/V *Thomas Washington* Sea Beam system.

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

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

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

ODF usually provides electronic profiling of the water column including acquisition and processing, and salinity, oxygen, and nutrient analyses and data processing, with occasional expeditions requiring large-volume sampling and radiocarbon extractions. ODF resources include a chemistry laboratory, an electronics shop, a CTD and deep sea reversing thermometer calibration laboratory, and a data processing and computer facility that supports both shipboard and shore-based processing, including real-time processing of CTD data. Electronics design work for many different applications is done routinely. The ODF onsite shop and laboratory facilities are augmented by the testing facilities at the Scripps Hydraulics Laboratory, and other Scripps facilities.

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

SSURF: SIO Supercomputer Users Remote Facility

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

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

Thomas Wayland Vaughan Aquarium-Museum

The aquarium-museum is the interpretive center for Scripps Institution of Oceanography, with the goals of increasing public understanding and wise use of global resources, and generating support for marine research. The facility features museum exhibits on oceanographic topics, a variety of educational programs, and displays of living marine animals from California, the Gulf of California, and the western tropical Pacific. This year more than 375,000 people visited the facility including 50,000 students in educational groups. The aquarium-museum is open to the public daily from 9:00 a.m. to 5:00 p.m. Admission is by donation: $3.00 is requested from adults, $2.00 from children 12-18 and senior citizens.

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

A new aquarium-museum, to be named Stephen Birch Aquarium-Museum in honor of the major donor, has been designed and is scheduled for opening in the fall of 1992. The new facility will be 3 times larger than the present one and include a substantial visitors parking lot. The project is expected to cost approximately $9 million, exclusive of parking and roads.

A $500,000 National Science Foundation grant has been awarded for the design and fabrication of the museum exhibit program.

Scripps Aquarium Associates, the aquarium-museum public membership group, offers ocean-related activities to its members, including local field trips, lectures, family activities, and collecting expeditions. A bimonthly calendar and a quarterly newsletter are provided.

Special Collections

Benthic Invertebrates
The collection contains some 40,000 lots of specimens sorted into major taxonomic groups such as Coelenterata, Echinodermata, Crustacea, and Mollusca. All are accessioned with collection data, and more than 35% are identified to species. Specimens, several catalogs of holdings (Decapod and Stomatopod Crustacea, Brachiopoda, and Echinodermata), and IBM-compatible dBase IV catalog data for various groups are available to qualified students and researchers.

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

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

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

Marine Invertebrates
Included in this collection of more than 53,000 documented whole zooplankton samples are accessioned holdings from expeditions, the continuing CalCOFI program, and special projects. Samples represent zooplankton collected with nets, ranging from surface neuston to bathypelagic midwater trawls. The major emphasis of the collection has been in the northeastern Pacific, but an increasing number of samples are also available from other oceanic and continental slope regions. The collection includes identified specimens for some of the major taxonomic groups. Most samples are supplemented with physical and chemical data.

Marine Vertebrates
This collection contains approximately 2.5 million specimens, with more than 4,000 cataloged species, including 165 primary types. Approximately 200 collections are added each year. Although the collection is worldwide, deep-sea and pelagic fishes and eastern Pacific shorefishes are emphasized. Included are large holdings of shorefishes from the Gulf of California and Panama, and an extensive skeletal collection of dried preparations and cleared-and-stained specimens in glycerin with more than 700 species represented. The otolith collection contains otoliths from 500 species.

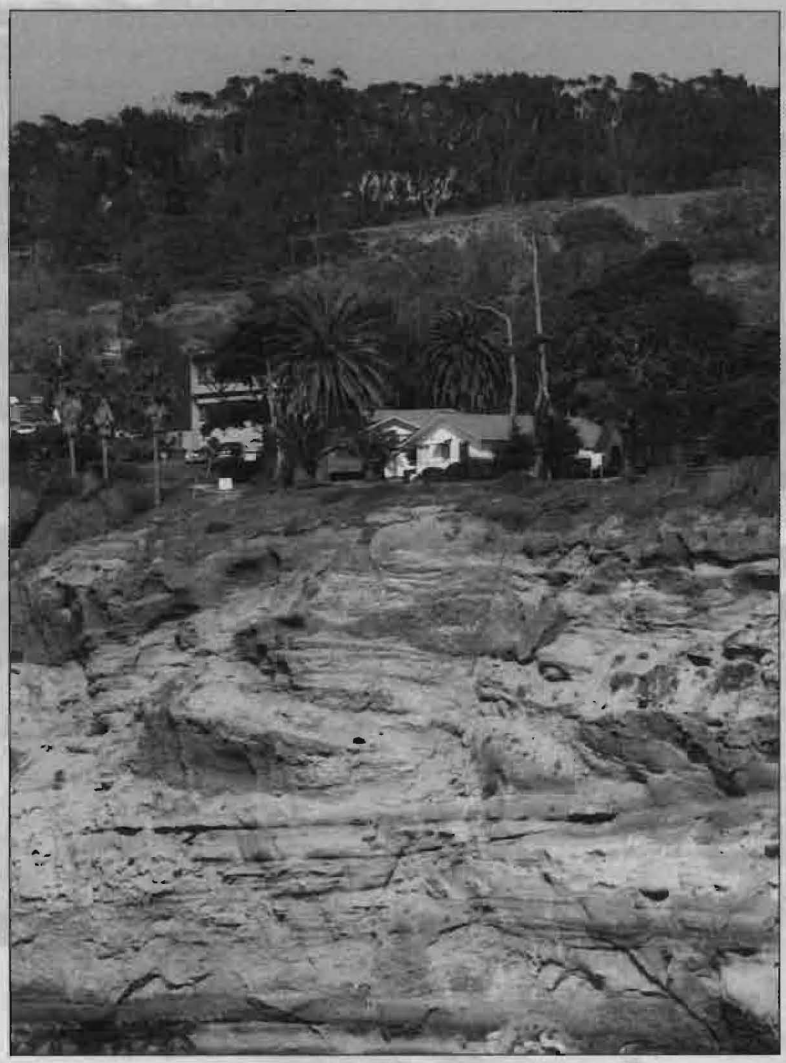
Oceanographic Data Archives
Tide-gauge records have been taken daily from the Scripps Pier since 1925. Monthly tide-gauge records from 1947 to 1967 and from 1980 to the present are available in the Scripps Library archives. Records before 1947 and from 1967 to 1980 can be obtained by writing the Chief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

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

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

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

A view of Scripps Institution of Oceanography from
Ellen Browning Scripps Pier.



APPENDIX A

Publications

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

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

Bulletin

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

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

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

CalCOFI Publications

The work of the California Cooperative Oceanic Fisheries Investigations (CalCOFI), in which the Scripps Institution of Oceanography, the California Department of Fish and Game, and the National Marine Fisheries Service cooperate, is published in a variety of formats. Peer-reviewed scientific articles are published annually in the *California Cooperative Oceanic Fisheries Investigations Reports*. Maps of physical, chemical, climatological, and biological factors measured by CalCOFI researchers during the program's 42-year history are published irregularly in the *California Cooperative Oceanic Fisheries Investigations Atlas* series. Data reports, containing the processed data from specific cruises carried out under CalCOFI sponsorship, are published irregularly in the SIO reference series and in the CalCOFI data report series. To obtain copies of any of these publications, write to **University of California, San Diego, Scripps Institution of Oceanography, CalCOFI Coordinator 0227, 9500 Gilman Drive, La Jolla, California 92093-0227.**

Contributions

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

The articles listed below were published in the 1990 volume and may also be found in the publications cited. Information about a specific reprint can be obtained by writing directly to the author in care of the **University of California, San Diego, Scripps Institution of Oceanography, 9500 Gilman Drive, La Jolla, California 92093.**

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CRD	Climate Research Division
CSI	California Space Institute
CCS	Center for Coastal Studies
DO	Director's Office
D-SIO	Department of the Scripps Institution of Oceanography
ECE	Electrical and Computer Engineering Department
GRD	Geological Research Division
IGPP	Institute of Geophysics and Planetary Physics
IMR	Institute of Marine Resources
IPAPS	Institute for Pure and Applied Physical Sciences
MBRD	Marine Biology Research Division
MLRG	Marine Life Research Group
MPL	Marine Physical Laboratory
MRD	Marine Research Division
NR	Natural Resources
NU	Neurobiology Unit
PORD	Physical Oceanography 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

APPENDIX C

Awards & Honors

Paul K. Dayton

Nominated to the United States Marine Mammal Commission by President George Bush.

J. Freeman Gilbert

Received a 1990 Balzan Prize from the International Balzan Foundation of Milan, Italy.

Miriam Kastner

Received an Ocean Science Educator Award from the Office of Naval Research.

Charles D. Keeling

Received the 1991 Maurice Ewing Medal from the American Geophysical Union.

William F. Perrin

Reappointed to the Marine Mammal Commission's Committee of Scientific Advisors.

Roger R. D. Revelle

Awarded the National Medal of Science by President George Bush.

Paul E. Smith

Received the United States Department of Commerce Gold Medal.

Fred N. Spiess

Received the Distinguished Public Service Award from the United States Navy.

James R. Stewart

Elected to the Diving Industry's Hall of Fame.

APPENDIX D

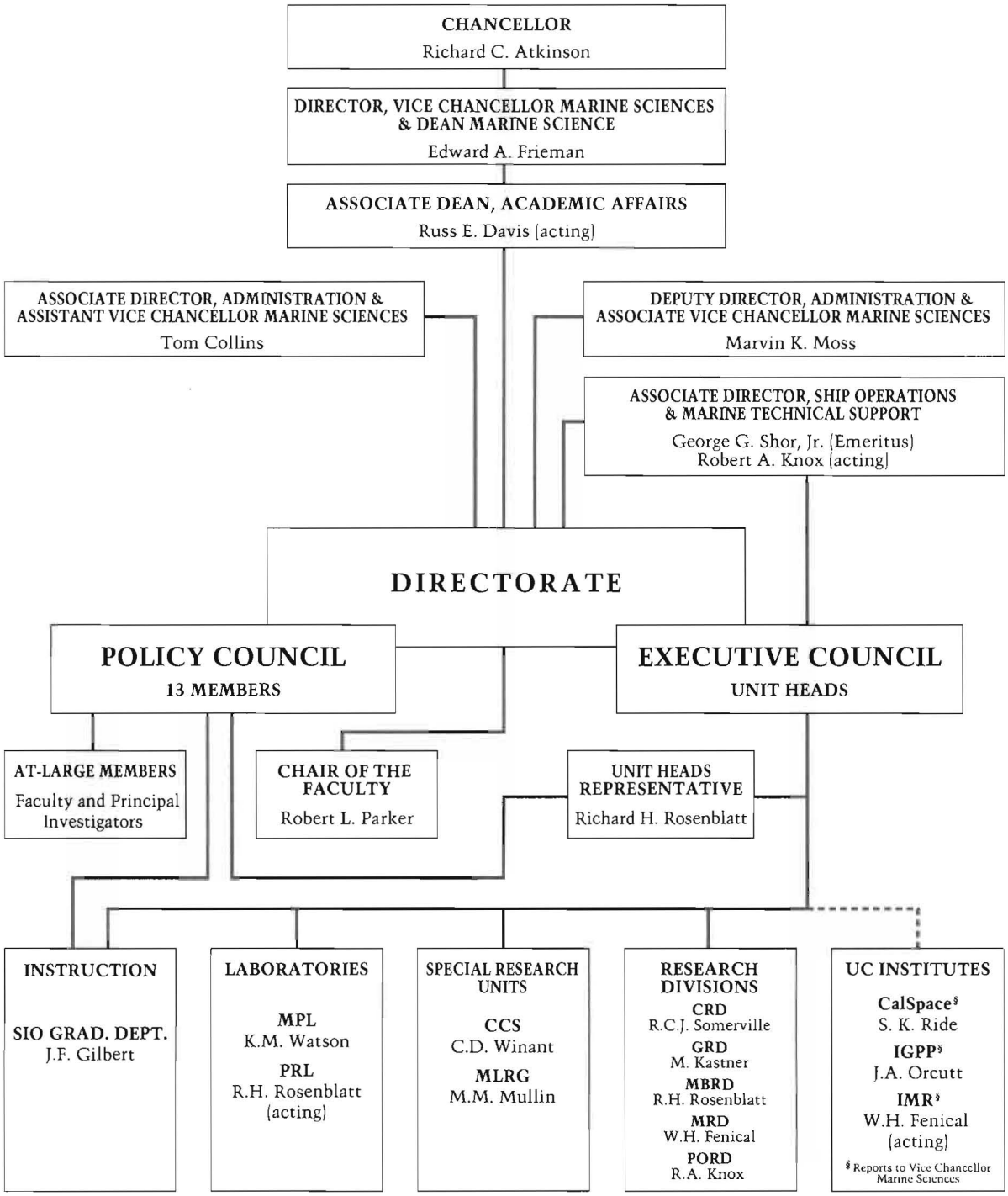
Current Funds

Agency	Expenditures*	Percent of Total
Federal Government		
National Science Foundation	16,247,902	22.40
Navy, Department of the	14,925,969	20.58
Commerce, Department of	2,374,599	3.27
National Aeronautics and Space Administration	2,436,800	3.36
Health and Human Services, Department of	1,223,550	1.69
Energy, Department of	1,103,349	1.52
Army, Department of the	1,873,572	2.58
Interior, Department of the	797,400	1.10
Air Force, Department of the	1,009,226	1.39
Other	386,369	0.53
Total Federal Government	**$42,378,736**	**58.42**
State General Funds	16,199,772	22.33
Private Gifts and Grants	8,959,678	12.35
Overhead Funds	1,680,959	2.32
State of California	890,284	1.23
Endowment Funds	398,385	0.55
Local Government	1,159	0.00
Sales and Services	538,485	0.74
Reserves	1,495,259	2.06
Total Current Funds Expenditures	**$72,542,717**	**100.00**

*Includes overhead

APPENDIX E

Organization*



CalSpace	California Space Institute	**MBRD**	Marine Biology Research Division
CCS	Center for Coastal Studies	**MLRG**	Marine Life Research Group
CRD	Climate Research Division	**MPL**	Marine Physical Laboratory
GRD	Geological Research Division	**MRD**	Marine Research Division
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John C. (Jack) Dullaghan. *November 10, 1990. Jack Dullaghan came to work at Scripps in 1958. He was Assistant Marine Superintendent (Engineering) at Nimitz Marine Facility from 1959 through 1977.*

Richard Porter Phillips. *March 22, 1991. Dr. Phillips received his Ph.D. from Scripps in 1964. He joined Scripps as a research associate from 1966 through 1973. He often volunteered on Scripps sea trips.*

Roger R. D. Revelle. *July 15, 1991. Dr. Revelle received his Ph.D. from Scripps in 1936, where he became an instructor until 1946. He advanced to professor in 1949. He returned to Scripps as associate director, was appointed acting director in 1950, and served as director of Scripps from 1951 through 1964. He returned to Scripps in 1990. In addition to founding UCSD and being one of the world's leading oceanographers, Dr. Revelle is described as the 'grandfather of the greenhouse effect' for his work in global warming.*

Don L. R. Seibert. *April 8, 1991. Don Seibert came to Scripps in 1967 and was an early member of Scripps Tuna Oceanography Research (STOR) group and specialist in the Institute of Marine Resources until his retirement in 1986.*

Richard A. Silva. *December 25, 1990. Rich Silva joined Scripps as an oiler in 1962, transferring in 1963 to the crew of R/P FLIP. In 1969 he took over as officer-in-charge until leaving in 1980. Rich Silva helped in the development of the deep ocean three point mooring capability.*

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