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Scripps Institution of Oceanography
Global Discoveries for Tomorrow’s World

Voyager
Insert for Kids!
See center of magazine

University of California, San Diego
**A Message from the Director**

Scripps Institution of Oceanography continues to lead the world in basic marine research and in the education of the next generation of oceanographers. The National Research Council of the National Academy of Sciences ranked Scripps first in faculty quality among all graduate oceanography programs in the United States. I believe this designation reflects the fundamental greatness of this institution and our faculty, our place in the world as a teaching and research center, and our positive contributions to society.

Being named “Number One” among oceanographic institutions does not mean we can rest on our laurels. We will continue to be challenged by our competitors, and we must remain agile and able to respond to the monumental changes occurring in science and in society. The institution cannot be tied to what is happening now, it must be positioned with a strong foundation of intellectual and material resources to continue its scientific leadership.

We appreciate attaining the National Research Council’s designation and title, but this past year has been a banner year for other reasons as well.

On April 20, 1995, I witnessed the dramatic launch of the new research vessel, Roger Revelle. This ship will join the Scripps fleet and continue our tradition of excellence in ocean science and at-sea research into the next century. She will provide a state-of-the-art resource for the oceanographic community and become a key instrument for
educating the next generation of seagoing scientists.

Accomplishments during the previous year included a six percent increase in our federal contract and grant revenues to $89.7 million (after a remarkable 82 percent increase over the past five years). The fact that Scripps continues to hold its own in awards as agency budgets diminish is attributable to the quality of our academic community.

The institution's total expenditures for fiscal 1994-1995 were just under one hundred million dollars. The significance of such a number becomes more meaningful by comparison. Over the past five years, total institutional expenditures have increased by 40 percent. Such a substantial increase is especially noteworthy because it occurred during a severe economic downturn for the state of California.

The strong spirit and hard work of all at Scripps have resulted in these remarkable accomplishments. I feel pride for our achievements and a sense of inspiration for what is possible.

Edward A. Frieman, Director
November 1995
“One of our greatest challenges is to effectively communicate the importance of science to all levels of society. For policymakers, there is a need for us to provide accurate, timely, and useful information. For the public, there is a need for us to establish linkages between scientific discoveries and improvements in the quality of life. For scientists, communication among research fields will result in a synergy leading to new approaches to problem solving.”
During the past four decades, Joe Curray has explored eons of geological history from ships, with scuba, on land, and at his drawing table. His research has revealed significant details about earth’s evolution and has provided enduring descriptions of how major geological features formed. Throughout, he has been a quiet, scholarly pacesetter whose congenial manner, high standards, and meticulous methods have earned him many scientific accolades and friendships.

A native of Cedar Rapids, Iowa, Curray earned a B.S. in geology at the California Institute of Technology (1949) and an M.S. in mineralogy at Pennsylvania State University (1951). He spent two years as a research geologist with an Oklahoma oil company—and when he left for Scripps, his intention was to earn a doctorate and return to oil exploration. But he found academic research and Scripps so exciting, he never left.

Curray’s thesis advisor was marine geology pioneer Francis Shepard, who had funding from oil companies to study sediments in the Gulf of Mexico. So Curray spent his first few expeditions working from shrimp boats and other fishing vessels. In 1959, he received his Ph.D in oceanography. By then, his interests had shifted from looking at individual sand grains for shape, size, and orientation to studies of the deposits themselves and how they form on continental shelves, slopes, and basins. Much of his subsequent research was done in collaboration with Shepard and David Moore, who was with the marine geology group at the Navy Electronics Laboratory on Point Loma.

Curray was a participant in the golden age of ocean exploration. He went on numerous expeditions of discovery to the continental margins of North and South America, Europe, Asia, and Australia, using seismic reflection to survey sediment structure. He was among the first to use scuba for making geological observations, diving along the California and South American coasts and on coral reefs and atolls of Micronesia and Panama.

On the Circe Expedition in 1968, Curray and Moore surveyed the basin of the Bay of Bengal in the Northeastern Indian Ocean. They encountered the world’s greatest pile of seafloor sediments, pouring from the Himalayan Mountains by way of the Ganges and Brahmaputra rivers, that forms a deep-sea fan up to 14 miles thick, running some 2,000 miles offshore.

For the following 25 years, Curray chose the Northeastern Indian Ocean and Southeast Asia as his principal interests. He participated in and directed various international collaborative studies through United Nations programs, utilizing British and Indonesian research ships and
making land surveys, to define the structure and evolution of the region. This led to studies of plate tectonics, focusing on the collision of India and Asia around 50 million years ago. His research is recorded in more than 100 research papers, in which are found many original descriptions of geological evolution.

Curray’s list of scientific advisory positions for governments and organizations is long and international. On campus, he served on and chaired most all academic committees and was chairman of both the Geological Research Division and the Graduate Department of SIO. One of his specialties was working with the Scripps Industrial Associates, and his efforts gave Scripps access to oil industry field data. Several scientific societies made him a fellow, and he received the Francis P. Shepard Medal from the Society of Economic Paleontologists and Mineralogists. Among his proudest legacies are his former students, many of whom have made significant contributions to academics and the oil industry.

Physical fitness is one of Curray’s life-long hobbies. He enjoys swimming, skiing, bicycling, and backpacking, but most of all running. As a student, he ran barefoot on the Scripps beach after body surfing. Then while working in Kuala Lumpur, Malaysia, he joined a local running society, the Hash House Harriers. In 1978 he organized a hash in La Jolla, and every Monday night since then the group has gathered, always ending their cross-country run with cold beer and camaraderie. He also found time to compete in several marathons and triathlons.

On weekends for nearly 30 years, Curray was part of a scuba and submersible diving company that conducted underwater geological and geophysical work for oil companies. In 1991, Curray became professor emeritus to “make the resources available for younger scientists.” In retirement, however, he continues work in his campus office on the geology of the Northeastern Indian Ocean and Southeast Asia with new field data coming in from oil companies and scientific colleagues. He lives in La Jolla with his wife, Mary Anne, who is also an athlete and avid runner.

Asked to recall a memorable moment at Scripps, Curray pondered and replied, “My whole experience here has been memorable—it has all been a thrill.”

DR. JOSEPH CURRAY AT WORK IN HIS SCRIPPS OFFICE
RESEARCH HIGHLIGHTS

The Research Highlights section presents an overview of the types of science and research conducted by the departments and divisions of Scripps. Each group chooses one scientist or project to highlight in their section each year. Readers interested in more in-depth coverage of the topics discussed here should consult the scientific papers listed in the Publications section.

CENTER FOR MARINE BIOTECHNOLOGY AND BIOMEDICINE

The Center for Marine Biotechnology and Biomedicine (CMBB), brings a multidisciplinary perspective to issues relevant to future exploration, utilization, and management of the untapped biological resources of the world’s oceans. Scientists in the center collaborate with colleagues in the departments of biology and chemistry at UC San Diego, and the departments of medicine, neuroscience, and pharmacology in the UC San Diego School of Medicine.

The CMBB program in marine biotechnology focuses on increasing the knowledge and application of chemical and molecular techniques in the study of marine biota. CMBB scientists’ research ranges from elucidation of the special properties of marine microbes—including those adapted to the deep sea—to the genetic engineering of commercially important species. Discovery and utilization of natural marine products with importance to medicine and industry also are emphasized.

Scientists stress basic research and training, and major cooperation with the biotechnology industry, particularly San Diego companies. CMBB researchers are committed to monitoring and managing the marine environment in order to expand the potential both for basic research and development of new technologies.

Dr. Bianca M. Brahamsha performs genetic research on the oxygenic, phototrophic cyanobacterium *Synechococcus*, which thrives at very high concentrations in nutrient-poor regions of the global oligotrophic ocean. Many strains of open-ocean *Synechococcus* are capable of swimming; however, unlike other swimming bacteria, they lack flagella. This phenomenon represents a novel type of prokaryotic motility and its mechanism remains mysterious.

Brahamsha and colleagues have identified an abundant cell-surface protein present only in motile strains of *Synechococcus*. Treating the cells with a protease, they have found that motility is abolished immediately and the abundance of the cell-surface protein decreases, leading the researchers to believe that the protein may be responsible for at least part of the apparatus of motility.

The group has created a genetic system for open-ocean cyanobacteria. Using gene transfer experiments with the bacterium *Escherichia coli*, they have cloned a gene for the cell-surface protein. They are in the process of inactivating the gene in order to create a mutant strain that no longer manufactures the protein, thereby determining whether it is involved in motility. As this protein seems to be found in all motile strains of *Synechococcus* and is absent in the nonmotile ones, it is as important from an ecological standpoint as it is from a genetic one.

Brahamsha and colleagues also have created an antibody for the protein and are hoping to use it in the field to identify and enumerate motile strains in various environments. They are interested in understanding the distribution of such strains in surface waters or deeper waters, and in determining whether the abundance of motile strains changes seasonally. This will help them determine whether they can correlate swimming ability with particular environmental variables, and perhaps provide a clue to the ecological advantage to the cell.

In another approach to the study of motility in *Synechococcus*, Brahamsha and the other researchers are using the genetic system they developed to create tagged mutations that abolish motility. Visiting student Klaus Stiefel is studying one of the motility mutants created in this way. He is in the process of recovering the wild type gene and will be sequencing it. Once the gene is identified, the group plans to compare it to others in the database and localize its product in the cell to understand the gene’s role in motility.
CLIMATE RESEARCH DIVISION

In the Climate Research Division (CRD), scientists study a broad range of phenomena, spanning time scales from a few weeks to several decades. Research themes include predicting the natural variability of climate and understanding the consequences of man-made increases in the greenhouse effect. In the climate system, the atmosphere, the seas, the land surface, and the world of living things are tightly coupled. To understand these interactions, a variety of expertise must be brought to bear through a team approach to research.

Current research projects include developing coupled global ocean and atmosphere models, assessing the role of cloud-radiation feedbacks in climate change, and modeling and predicting seasonal climate variability. CRD research combines the analysis of large observational data sets, the development of comprehensive numerical models of the climate system, and the use of satellite remote sensing capabilities for monitoring the entire planet. CRD scientists stress research on the regional and transient implications of global change on climate, emphasizing those aspects of climate that are potentially predictable.

Dr. Niklas Schneider is involved with the Atmospheric Radiation Measurements (ARM) program through which he seeks to understand and parameterize atmospheric radiation and its interaction with the surface temperature of the ocean. In this task, he employs a global coupled circulation model, a mathematical model for the earth's oceans, atmosphere, and their interaction. He is interested in the mechanics of global climate change, both natural and man made, and plans to use the model to identify and resolve discrepancies between observations and theory, and to point the way to new discoveries and research.

Schneider is currently studying the western Pacific warm pool, an area that features the warmest open ocean surface waters on the earth, with temperature in excess of 28°C, and that is, therefore, a key region for understanding the global climate. Using a climate model that predicts the ocean and atmospheric response within 60° latitude from the equator from the solar forcing at the top of the atmosphere, Schneider is particularly concerned with validating the ocean's heat budget, a measurement of the total inflow and outflow of heat in a system. He looks at all processes that influence upper ocean temperature including direct heating by the sun's radiation, and the distribution of this heat by the ocean's currents and turbulence. Results indicate that heating of the upper ocean by radiation that penetrates into the upper ocean layers is more important than previously thought and has significant effects on the vertical structure of ocean mixing.

Schneider is also investigating the Indonesian Through Flow, an ocean current that transports waters from the equatorial Pacific to the Indian Ocean through the Indonesian Archipelago. Schneider compares the predictions of the General Circulation Model with data from direct observations and quantifies the transport of water, its seasonal variations, the transport of heat, and the forcing of this current by atmospheric winds. He has found that the model simulates the transport in accordance with observations. While the wind stress over the Pacific determines the time averaged strength of this current, local winds over the Indonesian water dictate its seasonal cycle. Furthermore, the Indonesian Through Flow is a major contributor of heat to the Indian Ocean, consistent with observations and earlier model studies.

Looking toward the future, Schneider is in the process of creating a model of the atmosphere that includes the effect of diurnal variations of oceanic surface temperatures and their dependence on the atmospheric conditions. This model will indicate if there is a significant coupling of the short diurnal variability with the climate changes over longer times. Preliminary results indicate that the dynamics of the ocean do not supply such a coupling, but results regarding the role of the atmosphere are inconclusive at this time.
**GEOSCIENCES RESEARCH DIVISION**

Research in the Geosciences Research Division (GRD) addresses the broad areas of the physical and chemical processes in the earth’s mantle and crust especially in the seafloor, the interactions between the ocean and the atmosphere, and the reconstruction of ocean and climate history. Scientists carry out detailed studies concerning marine geology, petrology, tectonics, geophysics, isotope geology, geochemistry, remote sensing, mantle and crustal evolution, fluid processes, climate history, global biogeochemical cycles, global change, microfossil evolution and systematics, and marine, atmospheric, and solar system chemistry.

Dr. Christopher D. Charles studies the geologic record of climatic and oceanographic change. He hopes to elucidate how and why ancient climates changed and in the process answer critical questions concerning potential anthropogenic influence on present and future climate.

Using cores drilled from corals and deep-sea sediments, which act as geological archives, he looks at changes in the ocean over time scales from tens of years to thousands of years.

Corals act as paleo-thermometers because their compacted skeletons contain a passive record of years of climate variability as expressed by the effect of changes in ocean temperature on their skeletal chemistry. The cores are sliced, x-rayed, and dated; then small samples from different time periods are powdered and undergo mass spectrometer analysis. Isotope ratios in the resulting carbon dioxide gas are analyzed.

Isotopes are found in different ratios depending on specifics of the local climate. Thus Charles, working with post-doctoral researcher Michael Moore and students, deduces precise measures of historic salinity and temperature in the seawater. This type of record allows a widespread historical reconstruction of climate phenomena such as El Niño. These records could also provide a long historical baseline for determining the extent of global warming.

Charles also works with fossil records that go back hundreds of thousands of years. One as yet unsolved mystery of the climate system is why the ice age cycles, recurring every 100,000 years or so, were so strong. Charles seeks to address such questions, again by making use of isotope variations. In this case, the variations are recorded in deep-sea sediment.

Glacier ice contains a higher proportion of the isotope oxygen 16 (relative to oxygen 18) than does seawater. Thus when a glacier grows big enough, it leaves a relatively higher amount of 18O in seawater during ice age periods. Charles uses this information to obtain a precise chronology of the advance and retreat of ice age glaciers. Measurement of isotope records also can give historic climate information about ocean temperatures, deep ocean circulation, and nutrient cycling.

Results of Charles’s current studies, done in collaboration with colleagues at Columbia University, indicate that, contrary to past scientific speculation, tropical sea surface temperatures (SSTs) may have changed greatly over time. SSTs are considered to be the heat engine of world climate so this issue is of critical importance to historic climate studies.

Charles also has found global manifestations of changes in deep ocean circulation, thought to be another driving force in climate change. Based on the distributions of nutrients, CO2, productivity recorded in the ocean sediment cores, the global deep ocean circulation changed dramatically, along with glacial cycles. Charles is now working to explain what climate processes were involved and why these changes occurred.

Besides laboratory analyses of isotopic relationships in cores, Charles is involved in three-dimensional climate modeling and is working to incorporate isotope traces into computer models of simulations of past and future global climate.

Charles must travel to a variety of places to collect his coring samples. For example, he recently returned from a cruise to the far South Atlantic where he and colleagues spent six weeks collecting deep ocean sediment cores. Over the past few years he and colleagues have spent several months in the tropical Pacific and Indian oceans collecting corals and sponges in areas where Charles hopes to develop a network of sample sites to aid in delineating ocean climate variability over annual, interannual, and decadal time scales.
MARINE BIOLOGY RESEARCH DIVISION
Scientists in the Marine Biology Research Division (MBRD) investigate the ecological, physiological, cellular, and biochemical characteristics of marine bacteria, plants, and animals and the fundamental processes affecting life and energy flow in marine ecosystems. They examine organisms in a variety of habitats including the deep sea, coastal ecosystems, and Antarctica.

Ongoing studies include examination of the mechanisms of invertebrate egg and sperm interaction, and elucidation of the symbiotic relationships between diverse bacteria species and their invertebrate and fish hosts. Also being studied is the large-scale and long-term potential effects of global change on the productivity and diversity of marine ecosystems and on the distribution and abundance of marine organisms. Several MBRD scientists also are closely aligned with Scripps’s Center for Marine Biotechnology and Biomedicine.

Throughout much of the twentieth century, the fields of evolutionary biology and developmental biology were divided. Within the last few years, however, the two fields have united because of the unexpected discovery that the molecular machinery underlying development is remarkably similar in all animals. Among other things, the discovery has provided a powerful new tool for looking at homologies (similarities due to common ancestry) in distantly related animals. Two Scripps scientists—marine biologist Linda Z. Holland and her husband, Dr. Nicholas D. Holland—are using this new approach to study the origin of the vertebrates.

DR. NICHOLAS AND LINDA HOLLAND
The proximate invertebrate ancestor of the vertebrates has been extinct for half a billion years. Therefore, the Hollands are using a marine invertebrate called amphioxus as the best living substitute for the genuine ancestor. The amphioxus (or lancelet) is up to a few inches long, nearly transparent, and resembles an anchovy filet in appearance. There are few locations where amphioxus occur abundantly, and the most accessible population in North America lives on the west coast of Florida, burrowed in the shallow sands of Tampa Bay. It is there that the Hollands collect their specimens during the animals’ summer breeding season. Embryos and larvae are required for the work, which has been facilitated by Scripps graduate student Dale Stokes. A wealth of new information on the reproduction and development of the Florida amphioxus is included in Stokes’s Ph.D. dissertation.

Amphioxus is an invertebrate; yet it resembles primitive vertebrates in having pharyngeal gill slits, segmented muscles, and a dorsal nerve cord that is hollow. Although the Hollands are concerned with homologies in a variety of organ systems, the nervous system has been their main focus. Amphioxus is structurally so simple that anatomists have been unable to agree whether its nerve cord includes a region that can properly be called a brain. The Hollands have approached this problem by identifying genes in amphioxus that specify the same brain regions in a wide spectrum of animals. Some important developmental genes identifying brain regions in amphioxus are AmphiHox 3 in the middle of the large hindbrain, AmphiEngrailed at the midbrain/hindbrain boundary, and AmphiDistalless in the forebrain. Amphioxus appears to be a lot brainier than previously thought. The Hollands think that the brain of living amphioxus is much like that of cephalochordate fossils from which the vertebrates are thought to have originated.

The question of origin of the vertebrates is relevant to a wide range of biological issues. Recently, the Hollands have presented their results at meetings of evolutionary biologists, neurobiologists, developmental biologists, and vertebrate paleontologists. Because of the Hollands’ pioneering studies, amphioxus has become the experimental material for a world-wide group of biologists interested in developmental evolution. At present, there is an effort to find culture conditions that will induce amphioxus to breed throughout the year. If this can be achieved, amphioxus would be amenable to genetic manipulation and might well become standard laboratory animals as are fruitflies, mice, and zebrafish.
MARINE LIFE RESEARCH GROUP
The Marine Life Research Group cooperates with two other agencies—the California Department of Fish and Game and the Southwest Fisheries Science Center of the National Marine Fisheries Service—in the California Cooperative Oceanic Fisheries Investigations (CalCOFI) of the California Current System. This study provides one of the world’s most complete time series of data (more than 40 years) from an important oceanic ecosystem, permitting scientists to examine annual to decadal changes in the physics, chemistry, and ecology of an eastern boundary current system. The ongoing challenge to the collaborators is to incorporate new techniques, new concepts, and new societal concerns.

The data record has recently been used to show not only the effects of El Niño events on the populations in the California Current, but also a long-term decrease in the amount of zooplankton. On this longer time scale, the decrease must be related to very large-scale changes in underlying physical/chemical processes in the California Current.

For investigators outside the program the CalCOFI cruises provide a platform for biological oceanographic studies and also a base of environmental data from which to interpret their specialized measurements.

Research often leads MLRG scientists beyond the CalCOFI area. Dr. Teresa K. Chereskin specializes in direct velocity measurements of ocean currents. In recent years, she has participated in a number of cruises in the eastern Pacific and the Indian Ocean as part of the World Ocean Circulation Experiment (WOCE).

Recently, Chereskin found direct evidence for an Ekman balance in the California Current. Though the century-old Ekman theory, (which explains many of the larger features of wind-driven general circulation) is widely accepted, it has been very difficult to confirm. Two reasons for this, according to Chereskin, are the logistical difficulties inherent in making measurements in the upper ocean, and the observational barrier that results when wind-driven current signals are masked by pressure-driven current noise.

Over a four-month period of fortuitously steady southward winds, at a station roughly 483 km (300 mi) off the northern California coast, Chereskin conducted moored Acoustic Doppler Current Profiles (ADCP) velocity measurements and buoy wind observations.

If tested at this locale, the Ekman theory would predict that the effect of the rotation of the earth combined with the prevailing southward winds would result in a net offshore drift to the right of the wind (westward).

Chereskin separated the wind-driven flow from pressure-driven flow by subtraction of a deep reference current. (Hydrographic observations supported her interpretation of the reference current.) By removing the reference and averaging over time, she revealed a mean current spiral consistent with the prediction of Ekman’s theory. The Ekman theory also predicts that the direction of displacement will spiral with depth, and this too was borne out by Chereskin’s measurements.

In what she believes may be the most remarkable result of this experiment, an Ekman balance was observed on a daily timescale over a period of several months. Because a momentum balance between the Coriolis acceleration and the wind stress was observed, a vertical profile of the turbulent stress and the eddy viscosity could be directly inferred from the velocity observations.

Further south, in the Southern California Bight, Chereskin has been using a shipboard ADCP to create a time series that she hopes will accompany CalCOFI’s long-term database.

As WOCE has extended into the Indian Ocean, Chereskin’s interest there has been in shipboard and lowered ADCP’s deployed along a north Equatorial belt that is part of the only continuous global line that yields heat and freshwater budgets. The objective of a recent experiment was to gather current velocity measurements during the intense southwest monsoon of the western Indian Ocean. Chereskin reports that the Somali Current, which runs throughout the period of the monsoon, showed a peak velocity of six knots, driven by winds of up to 35 knots.
Scientists in the Marine Physical Laboratory (MPL) apply knowledge of the ocean and its boundaries to the solution of problems in five major areas: ocean acoustics, marine physics, marine geophysics, signal processing, and ocean technology.

Researchers in ocean acoustics quantify limitations the environment places on acoustic systems and how they affect the design, performance prediction, and operation of oceanographic systems. Scientists studying marine physics focus on the effects of the oceanic physical environment on undersea systems. They investigate large-scale eddy structures and small-scale internal waves and turbulence. MPL scientists also are interested in cloud cover and detection of surface and air targets through the marine atmosphere.

Marine geophysicists emphasize the basic physical processes and properties of the oceans, the substrate, and the ocean basins to clarify the environmental parameters affecting search, detection, and navigation sys-
tems. Research in signal processing encompasses all aspects of the collection, manipulation, and output of both analog and digital data including theoretical design, hardware fabrication, software development, and performance evaluation. Development of advanced ocean technology both for environmental measurement programs and for testing of new engineering concepts is another major MPL focus.

Dr. Jules S. Jaffe invents new instruments for in situ remote sensing of marine organisms in the water column. The goal of Jaffe's group is to develop new technologies to advance the study of ocean life.

One of the unresolved problems in oceanic biology is how matter and energy are transferred through food webs. To understand this process Jaffe has spent the last seven years developing new sensors to image both phytoplankton distributions and zooplankton behaviors on centimeter scales. This precision is needed to determine and understand the small scale patchiness of phytoplankton and the behavioral responses of zooplankton to that distribution.

Phytoplankton, at the base of the food chain, are preyed upon by some zooplankton. It is known that zooplankton move through large patches of phytoplankton as they feed, but it is not understood how individual zooplankters decide which paths to travel and which phytoplankton to eat. Many scientists believe that important aspects of the dynamics of populations within an ecosystem are regulated by individual behaviors. To understand these dynamics, scientists need to measure individual responses and behavior precisely.

To this end, Jaffe's group has developed and is honing an underwater optical imaging system called OSST (Optical Serial Section Tomography). OSST provides a three-dimensional image of phytoplankton distribution to centimeter scale resolution. In addition, a three-dimensional sonar system, FishTV, has been in operation for several years. This system reveals the three-dimensional trajectories of the zooplankton that feed upon phytoplankton, with centimeter accuracy in volumes as large as five cubic meters.

Last July, during a cruise with Scripps colleague Dr. Peter J. Franks, Jaffe deployed both the OSST and the FishTV system. Jaffe's initial findings indicate that small-scale phytoplankton distribution is much more variable than previously suspected. In addition, the sonar data indicate that the distribution of the animals is highly correlated with that of the phytoplankton. These findings, coupled with more thorough processing of these data in the future, will enhance the understanding of how matter and energy are transferred through the marine food web.
MRD scientists are investigating the large-scale circulation of the South Atlantic Ocean, studying the characteristics of the earth's earliest ocean and atmosphere, and elucidating the organic carbon cycling in the oligotrophic gyres of the North Atlantic and Pacific oceans.

They study theoretical and applied problems in marine optics, the geochemistry of borehole fluids, the natural products chemistry of marine invertebrates and marine bacteria, and the role of bioactive chemicals in the marine environment. Researchers also focus on the medical and pharmaceutical applications of marine organisms.

Several researchers at MRD are investigating the inhibition of red-tide dinoflagellate growth in the Santa Cruz Harbor, California, and the performance of a breakwater at Fisherman's Wharf in San Francisco Bay. Other scientists at MRD concentrate on the Antarctic coastal ecosystem.

Dr. Jeffrey L. Bada is studying the accretion of organic material on primitive Earth, and is conducting a search of seawater, polar ice, lunar soils, and meteorites from Mars for exogenous (extraterrestrial) organic compounds. He concentrates on the detection of \( \alpha \)-amino-isobutyric acid (Aib) because it is one of the most abundant amino acids in carbonaceous meteorites, is readily synthesized in abiotic experiments, and is not found in the proteins of modern organisms.

To evaluate whether the delivery of exogenous organics can be detected on the earth today, Bada and his colleagues have searched for extraterrestrial amino acids in polar ice, the most organically uncontaminated reservoir on Earth. No detectable amounts of Aib have been found in more than 20 polar-ice samples, with one exception; an approximately 4,750-year-old sample from Greenland. Comparative analysis with the 1968 Murchison meteorite—which fell in Australia—and with the amino acids derived from hydrogen cyanide, a major comet component, suggest that Aib in the Greenland ice sample may have originated from a comet.

The Bada group also has directly assessed the delivery to modern Earth of exogenous organics associated with interplanetary dust particles (IDPs). Antarctic ice is an excellent repository of IDPs and micrometeorites, and milligram-size samples can be recovered by melting large amounts of ice. The group has obtained 60 samples of Antarctic micrometeorites; half were melted during atmospheric entry, and half were not. Their analyses have revealed that the melted samples were devoid of amino acids, while the unmelted samples were rich in Aib. The group's findings support the suggestions of others that the Antarctic micrometeorites may be comet debris, which is richer in organics than carbonaceous chondrites. Bada's group is now evaluating whether this micrometeorite material could have supplied early Earth with a rich inventory of organic compounds.

Turning to questions regarding early DNA, the group has investigated the extent of amino-acid racemization and DNA preservation in natural samples ranging in age from the present to 120 million years ago. They found that the amino acid racemization rate among insects entombed in amber is significantly slowed in comparison to most geochemical environments. The decreased racemization for such insects is apparently caused by the anhydrous nature of the amber matrix. According to Bada, DNA depurination rates in these insects should also be slowed in comparison to hydrous geochemical conditions.

His conclusion has proven consistent with the reported successful retrieval of DNA sequences from organisms encased in amber as old as 120 million years. Bada believes that amino acid racemization may be useful in predicting where on Mars DNA-like molecules from an extinct Martian biota might best be preserved.
NEUROBIOLOGY UNIT
The survival, success, distribution, and ecological role of animals depend on sensing the environment, integrating, calculating, interpreting, and recognizing stimuli, and controlling adaptive behavior. The Neurobiology Unit (NU) is a group of several laboratories at Scripps that focus on the nervous systems, sense organs, and behavioral mechanisms of animals. NU scientists participate in the Center for Marine Biotechnology and Biomedicine and some are associated with the UC San Diego School of Medicine.

In the laboratory of Dr. R. Glenn Northcutt, Chris Braun, a graduate student in the UC San Diego Department of Neurosciences, is studying the sensory systems of certain fishes. He investigates these systems in specific species of hagfish (a benthic, burrowing fish) and lampreys (a free swimming fish) to understand how they have evolved to reflect the animals’ environments and ways of life.

Taste and lateral line systems are of the greatest interest to Braun. The lateral line system consists of a longitudinal series of sensory organs, oriented along both sides of a fish’s body, which detect small water movements around the fish. This allows fish to determine their physical orientation and detect possible prey and predators in the environment. Braun uses neuroanatomical techniques to study the structure and distribution of sensory organs on the skin surface and how they hook up to the brain.

Through his investigations, Braun has determined that the hagfish species Eptatretus stouti has an incredibly elaborate sense of taste—a previously unappreciated fact. The entire body of the hagfish is covered with taste buds, which optimize food detection in the dark and muddy environment. Other species, such as catfish, which occupy this type of environment have long been considered to be expert tasters. Because the hagfish is a burrower and not exposed to water movements, it has a poorly developed lateral line system.

Braun also studies Ichthyomyzon unicuspis, a species of North American lamprey. Lampreys have an endobenthic larval stage and after metamorphosis become free swimming and are found in coastal regions. Following metamorphosis, lampreys have well developed eyes and lateral line systems, but poorly developed taste buds. In their free-swimming lifestyle, lampreys depend more on sight and water vibrations than taste buds.

Both lampreys and the hagfishes belong to ancient lineages. Lampreys have remained similar to their ancient ancestors, while the hagfishes have developed elaborate sensory organs possibly the result of environmental influences.
PhysicAl Oceanography Research Division

Scientists in the Physical Oceanography Research Division (PORD) study a range of observational and theoretical topics related to the physics of the ocean. Many of the PORD investigators hold joint appointments in other areas at Scripps, which provides for diversity of research and opportunities for cross-disciplinary communication.

Some PORD researchers study the large-scale circulation of the world's oceans or the specifics of smaller environments such as the continental shelf, marginal seas, straits, estuaries, or the surf zone of open shorelines. Others examine the interaction between the ocean and the atmosphere. Theoretical studies range from classical fluid dynamics problems to models of large-scale ocean circulation or the atmospheric marine boundary layer. PORD scientists also develop new sensors and measurement technology for ocean studies such as autonomous drifters, bottom pressure and electromagnetic sensors, and new versions of Acoustic Doppler Current Profilers.

Three studies that attempt to quantify specifics of ocean/atmosphere interaction and circulation of ocean waters are the focus of Dr. Dan L. Rudnick's research. Aided by state-of-the-art technical equipment, Rudnick hopes to validate hypotheses that concern the mechanics of ocean mixing, subduction, and the path of deep currents—processes that ultimately influence world climate.

Rudnick is part of a major study called the Subduction Experiment in which scientists seek to delineate the specific mechanisms by which layers of surface water are subducted, or transported deeper into the ocean. It is known that surface water subducts at areas of upper ocean fronts, boundaries between dissimilar water masses. Upper water layers—subject to solar radiation—are warmer, so scientists can quantify how much and how fast subduction takes place by tracing the transport of heat through the water column.

Rudnick collects these data with SeaSoar, a remotely controlled hydroplane that is equipped with a CTD for taking temperature, salinity, and pressure measurements; and a fluorometer, which quantifies fluorescence—an index of phytoplankton density. Attached to a host ship like Scripps's R/V Robert Gordon Sproul by 460 m (1509 ft) of cable, SeaSoar can be towed for weeks to collect data passively. Also, Rudnick can actively control SeaSoar's wings to sustain a fast 8 knots and carry out diving maneuvers to 330 m (1083 ft).

Using a marine satellite system, which relays images to computers on board ship, Rudnick is able to pinpoint fronts for study. With temperature and density measurements supplied by CTD, he can remotely steer SeaSoar from the ship to follow the course of isotherms of subducted waters. Individual survey swaths are
joined by computers to give a broad picture of the subduction phenomenon. This procedure is both quicker and has a higher resolution than techniques previously available.

Rudnick took part in three cruises this past year as a member of the Arabian Sea Process Experiment, a study of how ocean currents and temperatures change in response to monsoon conditions. He hopes to quantify processes involved in heat flux and momentum flux from the atmosphere to the ocean and operations involved in the mixing and sinking of surface waters.

Two moored instrument buoys transfer near real-time data via satellite from stations in the Arabian Sea to Rudnick's office at Scripps. The buoys record temperature, pressure, wind, and solar radiation data from the atmosphere, and ocean temperature and current data from beneath the water to 150 m (492 ft) deep.

A third experiment involves Rudnick in the study of water movement through the Samoan Passage, a so-called "choke point" in the global General Circulation. It is known that deep water from the South Pacific travels to the North Pacific through this deep ocean channel, but questions remain concerning the magnitude and variation of its flow. Rudnick deployed subsurface moorings that recorded data for eighteen months. He has quantified a large monthly fluctuation and hypothesizes a rebound effect stemming from having more water trying to pour through a small passage than can be accommodated at once.
The Center for Coastal Studies (CCS) is an interdisciplinary research center focused on the physical and sedimentary processes along the coastlines of the world. Research at CCS concerns fluid-sediment interactions responsible for sand transport along beaches and over the continental shelf; processes affecting circulation of coastal waters, circulation in semi-enclosed seas, and in the straits that connect them to larger ocean basins; coastal meteorology, surface gravity waves, and wave-induced currents in shallow water; and sediment management in harbors and estuaries. CCS also manages the Hydraulics Laboratory.

Recent CCS research has concerned beach or shelf processes in the Santa Barbara Channel, offshore of North Carolina and southern California, within San Francisco and San Diego bays, in the Nile Delta, and in the Indonesian Archipelago.

The foundation for CCS was laid by Dr. Douglas L. Inman twenty-five years ago. He formed the Shore Processes Study Group at Scripps and ten years later the group became CCS, with Inman as its director—a post he held until 1987. Now a research professor of oceanography, Inman is creating and perfecting methods for studying coastal processes such as beach erosion and sediment transport.

Along with Dr. Scott A. Jenkins, Inman is designing conceptual and numerical models of nearshore processes for five types of coastal areas: collision coasts that occur along active plate margins; trailing-edge coasts that develop on the back edge of a land mass that moves with the plate; marginal sea coasts that form along shores of enclosed seas; arctic coasts that are molded by wave action and ice push; and coral reef coasts that form as an interactive response between waves and organisms.

The basis for these models is decades of observations made by Inman of the world's coastlines. During his career he has visited nearly every coastal area across the globe; and he has learned that similarities exist among all coastal areas. Forcing functions, including waves, tides, and currents, and how they interact with sediment, are basically the same the world over. What differs is the relative magnitude of these processes. By building a model that encompasses the inherent similarities and differences among coasts and that accounts for specific variations in those coasts, any coastline can be modeled.

The benefit of this type of modeling is that the same model used to simulate the coastline in La Jolla, California, could be used, with modifications, for another coastline by resetting the model inputs rather than rebuilding the model. Future funding and partnerships with industry will provide avenues to perfect these coastal models. Inman's goal is to provide a model that can be used by industry, government, and the private sector across the world to predict the future of coastal areas.

One model currently under development, which the scientists plan to integrate into the larger models, is used to simulate the scour and burial of objects on the coastal ocean floor. The root of this research, funded by the Office of Naval Research, is a 1953 pilot study done by Inman for the Navy. Aided by modern computer modeling, Inman is using his old data to develop new algorithms for studying scour and burial phenomena. Inman and Jenkins will place replicas of modern mines at different depths to study how waves and currents cause scour holes around them. After time, the mines roll over into the scour holes and then become covered by moving sediment.

The research applications that most interest Inman and Jenkins are predicting scour and burial effects on other forms, such as seawalls, breakwaters, and pipelines and understanding the burial cycle of cobble fields that ruin beaches, clog lagoon inlets, and cause significant coastal damage.
C A L I F O R N I A  S P A C E  I N S T I T U T E  

The California Space Institute (CalSpace) is a multi-campus research unit of the University of California, which supports space and Earth related sciences, education, and technology research. CalSpace maintains close ties with many departments both at UC San Diego and other UC campuses through scientific collaboration and joint faculty appointments. CalSpace researchers conduct both pure and applied research in interdisciplinary fields.

CalSpace scientists at Scripps investigate both the mechanisms of Earth systems and their sensitivity to human activity and intervention. They study the fundamental aspects of climate dynamics and global change caused by both natural and human forces, including ocean-atmosphere interactions, the role of clouds in climate, hydrological cycle processes, and oceanic and atmospheric circulation patterns. Large observational data sets, comprehensive numerical climate system models and data from satellite remote sensing are utilized in this research process.

Dr. William D. Collins's research takes him from the Indian Ocean, to Oklahoma, to the tropical Pacific in search of a better understanding of global weather conditions—including issues as diverse as the dynamics of El Niños, man-made pollution on climate, the greenhouse effect, and the role of clouds in climate. He is involved in the Central Equatorial Pacific Experiment (CEPEX) that seeks to determine the effects of clouds on the climate in the tropical Pacific. Over the ocean, the greenhouse effect is part of a climatologic loop in which increases in water vapor (an atmospheric greenhouse gas) result in higher sea surface temperatures (SST). The higher SSTs lead to a moister atmosphere through a variety of natural processes, including evaporation and the transport of water vapor from distant ocean regions. This increases the greenhouse effect and ultimately further raises the sea surface temperature. This feedback system is important in climate research because it can enhance the global warming caused by man-made pollutants.

Collins and his colleagues have hypothesized an additional mechanism that enhances this loop—called the super greenhouse effect. They believe that elevation of SST also increases convective clouds and introduces water vapor into the upper atmosphere—where it greatly enhances the greenhouse effect. Data gathering by stacked aircraft—research craft that fly directly above each other at different altitudes—have provided data that support this thesis.

Traditional theory holds that evaporation is the main cooling element, or negative feedback, in this cycle. Collins and his colleagues believe that cirrus clouds alone are enough to provide negative feedback and are more important than evaporation. Thin cirrus clouds can, and do, act as a blanket (trapping some of the heat from the earth's surface before it is emitted to space) and raise the SST. However, thicker cirrus clouds act more like a shade than a blanket and block solar radiation from reaching Earth's surface (and thus decrease the SST). Recent data collected by CEPEX seem to confirm the cloud shading effect at the ocean surface as the dominant negative feedback in the tropical Pacific climate.

A second large study in which Collins is involved combines CEPEX data with data from the Tropical Ocean Global Atmosphere/Coupled Ocean Atmosphere Response Experiment (TOGA/COARE) to test the predictive accuracy of atmospheric General Circulation Models (GCMs). These models are used to simulate atmospheric weather patterns and the response of the climate to changing surface temperatures and atmospheric composition. The Tropical Pacific can be considered a “flywheel” for the global climate energy entering and leaving the earth's atmosphere. The discrepancy between model predictions and actual data currently being collected can run as high as 50 percent; Collins and his colleagues use the CEPEX/COARE data to correct the GCMs. Collins is preparing to run several leading GCMs on a new massively parallel supercomputer recently installed at the San Diego Supercomputer Center.

Collins is also participating in the ARM Enhanced Shortwave Experiment (ARESE), a new initiative of the DOE Atmospheric Radiation Measurement (ARM) program. The experiment is being conducted at the Clouds and Radiation Testbed (CART) site in Oklahoma, a unique facility, which provides complex instrumentation for measuring a wide variety of atmospheric processes over a large region. The goal of ARESE is to test recent scientific reports that clouds absorb much more sunlight than previously thought. If ARESE confirms these reports, existing models of energy transport in the ocean and atmosphere will need revision. Collins is working with teams lead by Francisco Valero and Veerabhadran Ramanathan of Scripps. They are studying the solar radiative flux using aircraft and satellites. Collins hopes to use the findings from ARESE to further refine GCMs and improve the accuracy of climate change projections.
John declassified in 1995, making a group was steered toward Navy's of altimetry gathered by the as a result of MEDEA's efforts, MEDEA, a group of government officials and scientists led by Vice President Al Gore, began to explore the potential scientific utility of then previously unknown seafloor features. This branch is part of the University of California systemwide IGPP and houses the systemwide office. Other IGPP branches are located at the Los Angeles and Riverside campuses and at the Los Alamos and Lawrence Livermore national laboratories.

IGPP research at Scripps spans many disciplines, including seismology, geodesy, geomagnetism, global seismic networks, fluid mechanics, marine acoustics, marine geophysics, geodynamics, space physics, nonlinear dynamics, and theoretical geophysics.

Dr. David T. Sandwell is researching the geological structures of deep-ocean basins using satellite altimetry and shipboard mapping techniques. His current research is focused on understanding the poorly charted areas of the South Pacific, a remote region where satellite altimetry is proving to be a valuable aid.

Profiles from orbiting satellites, collected over many years, are combined by Sandwell and other researchers to make high-resolution images of sea-surface heights. These, in turn, are used to generate images of the corresponding features of the seafloor.

MEDEA, a group of government officials and scientists led by Vice President Al Gore, began to explore the potential scientific utility of then classified satellite data from this area in the early 1990s. MEDEA was chaired by Dr. Gordon MacDonald of UC San Diego and included Scripps Director Dr. Edward Frieman and IGPP researchers Drs. John Orcutt and Walter Munk. This group was steered toward U.S. Navy data by Admiral Paul Gaffney and, as a result of MEDEA's efforts, altimetry gathered by the U.S. Navy's GEOSAT program was declassified in 1995, making a wealth of data available to scientists.

Geodynamic applications of these data now include: location of uncharted features for planning detailed shipboard surveys and improving bathymetric charts; investigation of seafloor morphology and isostasy; identification of fracture zone trends for improving plate reconstruction models; determination of the global distribution and loading histories of undersea volcanoes; and location of marine sedimentary basins for hydrocarbon exploration.

Since declassification, data from the U.S. Navy's GEOSAT and the European Space Agency's ERS-1 altimeters have provided scientists with the most comprehensive measurements of sea-surface heights thus far. GEOSAT can map sea-surface heights at a horizontal resolution of 10-15 km (6-10 mi) and a vertical resolution of 2.54 cm (1 in).

Launched by the Navy in 1985, GEOSAT was placed in a nearly polar orbit to obtain high-latitude coverage (± 72° latitude). This range has proven particularly valuable to Sandwell and colleagues by providing them with much-needed data on sea-surface heights in the remote South Pacific. Images constructed from data gathered over this region reflect many seafloor structures that have been associated with plate tectonic activity, another focus of research at IGPP.

Satellite altimetry in many cases has enabled researchers to discover previously unknown seafloor features and has helped to elucidate the history of tectonic activity around them. Sandwell and Scripps researcher Dr. Peter F. Lonsdale went to the Eltanin Fracture Zone to conduct detailed surveys using shipboard swath-mapping techniques guided by previously declassified GEOSAT data for the southern latitudes.

According to Sandwell, the clear resolution provided by satellite altimetry gives significant new information about ocean-floor topography, especially in the remote southern oceans where the typical spacing between shipboard bathymetric profiles is more than 100 km (62 mi). The total swath width of a multibeam mapping system on a ship is 10-15 km (6-9 mi), so the sea-surface height maps provided by satellite altimetry are the perfect reconnaissance tool for planning more detailed shipboard surveys, a number of which have been proposed by Sandwell and colleagues for the near future.
**GRADUATE PROGRAM**

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 eight curricular programs through which the student may pursue a Ph.D. degree. Each of these curricular groups has prerequisites for admission in addition to the departmental requirements. The curricular programs are described below.

**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, biogeography, and physical-biological interactions.

**CLIMATE SCIENCES**

Climate sciences concerns the study of the climate system of the earth with emphasis on the physical, dynamical, and chemical interactions of the atmosphere, ocean, land, ice, and the terrestrial and marine biospheres. The program encompasses changes on seasonal to interannual time scales and those induced by human activities, as well as paleoclimatic changes on time scales from centuries to millions of years. Examples of current research include: interannual climate variability; physics and dynamics of El Niño; studies of present and future changes in the chemical composition of the atmosphere in relation to global warming and ozone depletion; effects of cloud and cloud feedbacks in the climate system; paleoclimate reconstructions from ice cores, banded corals, tree-rings, and deep-sea sediments; the origin of ice ages; air-sea interactions; climate theory; and terrestrial and marine ecosystem response to global change.

**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 include...
are marine geology and geophysics, tectonics, sedimentology, micropaleontology and paleoceanography, petrology and geochemistry, and isotope geology. Expedition work at sea and field work on land are emphasized as essential complements to laboratory and theoretical studies.

**GEOPHYSICS**

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

**MARINE BIOLOGY**

The marine biology curriculum emphasizes the basic biology of marine organisms—animals, plants, and prokaryotes. Research and teaching emphasize a broad range of biological disciplines, including molecular biology, microbiology, comparative physiology and biochemistry, developmental biology, neurobiology, biomechanics, evolution, systematics, behavior, and ecology.

**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 1994, 36 new students were admitted to graduate study. Of these, 7 were in marine biology, 5 in geological sciences, 6 in geochemistry and marine chemistry, 3 in geophysics, 4 in physical oceanography, 7 in applied ocean sciences, and 4 in biological oceanography. The newest curricular group, climate sciences, will begin accepting students in 1996. Enrollment at the beginning of the academic year was 184. UC San Diego awarded 22 Doctor of Philosophy degrees and 8 Master of Science degrees to the students listed in this section.

**GRADUATE STUDENTS AND DEGREE RECIPIENTS**

*Doctor of Philosophy Degrees Awarded, with Titles of Dissertations*

**Earth Sciences**

Catherine Johnson, “The Geomagnetic Field over the Last 5 Myr from Lava Flows and Properties of the Venusian Lithosphere from Magellan Data.”

Maria Tolstoy, “A Comparison of Slow and Fast Spreading Ridge Axis Structure from Seismic Data.”

**Marine Biology**


Peter A. Fields, “Adaptation to Environmental Temperature in Two Genera of Coastal Fishes, Paralabrax and Gillichthys.”

Ute Hentschel, “Nitrate Respiration in Chemoautotrophic Symbioses.”

Yoon Lee, “Microbial Oxidation of Cobalt: Characterization and Its Significance in Marine Environments.”

Youn-Ho Lee, “Abalone Sperm Lysin: Molecular Evolution of a Fertilization Protein, Implications Concerning the Species-Specificity of Fertilization and Speciation in Marine Invertebrates.”

David C. Smith, “Bacterial Decomposition of Marine Aggregates and Its Biogeochemical Significance.”
**Oceanography**
Luann Becker, “The Nature of Fullerenes.”

Kenong Bi, “Variability of the Surface Layer Circulation in the Western Equatorial Pacific.”

Wayne C. Crawford, “Determination of Oceanic Shear Velocity Structure from Seafloor Compliance Measurements.”

Hae Jin Jeong, “The Interactions between Microzooplanktonic Grazers and Dinoflagellates Causing Red Tides in the Open Coastal Waters off Southern California.”


Sean McNamara, “Kinetics of Granular Media.”


Howard Jesse Smith, “The Boron Isotopic Composition of Ocean Crust.”

Eric W. Vetter, Jr., “Southern California Nebalia; Ecology, Production, Natural History and Systematics of Two Subtidal Species.”

Chen-Feng You, “Lithium, Beryllium, and Boron Isotope Geochemistry: Implications for Fluid Processes in Convergent Margins.”

Xiaojun Yuan, “Characteristics and Frontogenesis of the Subarctic Front in the North Pacific.”


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**Master of Science Degrees**

**Earth Sciences**
Valerie K. Otero
Lois C. Yu

**Marine Biology**
Holly H. Ganz
Angelica I. Garcia-Rodriguez

**Oceanography**
Signe K. Christensen
Guanmei Liu
Jerald W. Mullison
Michelle G. Pruitt

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.
R/V ROGER REVELLE
DOCKSIDE FOLLOWING
LAUNCHING CEREMONY
IN MISSISSIPPI IN
APRIL 1995
SEAGOING OPERATIONS

One of the main tools in the study of the ocean is our oceanographic fleet, which is made up of three research vessels and two platforms. Our fleet traveled more than 100,034 nautical miles in fiscal year 1994-1995 and operated a total of 860 days.

R/V Melville

Eleven chief scientists led nine expedition legs aboard R/V Melville during the fiscal year 1994-1995. Research sites included the waters off Mexico, South America, Tonga, Fiji, New Zealand, Australia, and Tasmania. Research activities included OBS deployment, geophysical surveys, Sea Beam data collection, dredging, deployment of moorings, CTD stations, water sampling, ALACE drifter deployment, iron enrichment experiments, and Deep-Tow operations. Other institutions conducting research aboard R/V Melville included Lamont-Doherty Earth Observatory, University of Hawaii, Duke University, and Moss Landing Marine Laboratories. The regular captain was Thomas Desjardins. Relief captain was Eric Buck.

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**R/V New Horizon**

Fifteen chief scientists led 22 scientific explorations aboard R/V New Horizon during the 1994-1995 fiscal year. More than fifteen different experiments and research activities took place, including radiocarbon analyses, air-sea gas transfer measurements, phytoplankton studies, OBS and mooring recovery, seafloor geodesy, CalCOFI studies, equipment testing, sediment trap recoveries, hydrothermal vent exploration, gravity studies, and benthic biology. Scripps professors conducted two class cruises aboard R/V New Horizon. Research destinations included the Juan de Fuca Ridge, the Southern California Bight, Los Angeles Harbor, Point Conception, the eastern tropical Pacific, and the waters off Santa Barbara and San Diego. Other institutions conducting research aboard the ship included the University of Toronto, University of Southern California, Woods Hole Oceanographic Institution, and UC Irvine. Christopher Curl was the regular captain, with John Manion, Curtis Johnson, and Albert Arsenault as relief captains.

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<td>Operating Days</td>
<td>259</td>
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**R/V Robert Gordon Sproul**

Twenty-two chief scientists embarked on 41 research projects aboard R/V Robert Gordon Sproul during the 1994-1995 fiscal year. The ship traveled from the waters off San Diego to the Santa Barbara Channel, Monterey Bay, the Southern California Bight, Los Angeles Harbor, and the Columbia River. Research efforts included ambient noise studies, biogeochemistry, tiltmeter tests, clam collection, circulation studies on the continental shelf, meteorology, research on upwelling fronts, physiological studies, shark studies, benthic biology, and red tide bloom sampling. A variety of other institutions conducted research aboard this ship, including Woods Hole Oceanographic Institution, UC Davis, Monterey Bay Aquarium Research Institute, University of Southern California, Rutgers University, NRIAD, University of Washington, and University of San Diego. Louis Zimm was captain.

<table>
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<td>Operating Days</td>
<td>149</td>
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</tbody>
</table>
R/P FLIP

R/P FLIP was towed to sea nine times this year for a variety of research endeavors, including ATOC studies and data collection for the SWellEx. Six chief scientists from Scripps and other institutions, such as UC Irvine and Applied Physics Laboratory, led trips this year. Terry Hoopes was the officer in charge, relieved by Athanasios Golfinos. During the 1994-1995 fiscal year FLIP underwent a complete overhaul, receiving major repairs, electrical upgrades, and habitability improvements.

R/P ORB

R/P ORB was not operated during the 1994-1995 fiscal year.

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**R/P FLIP**

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<th>Type</th>
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<tr>
<td>Range (nautical miles)</td>
<td>varies*</td>
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<tr>
<td>Crew</td>
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<td>Operating Days</td>
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**R/P ORB**

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<tbody>
<tr>
<td>Yr. Built</td>
<td>1967</td>
</tr>
<tr>
<td>Yr. Acquired by Scripps</td>
<td>1968</td>
</tr>
<tr>
<td>Owner</td>
<td>U.S. Navy</td>
</tr>
<tr>
<td>Length</td>
<td>69'</td>
</tr>
<tr>
<td>Beam</td>
<td>45'</td>
</tr>
<tr>
<td>Draft, fwd</td>
<td>4'10.5&quot;/aft 5'4.5&quot;</td>
</tr>
<tr>
<td>Displacement, full (tons)</td>
<td>325</td>
</tr>
<tr>
<td>Cruising Speed (knots)</td>
<td>varies*</td>
</tr>
<tr>
<td>Range (nautical miles)</td>
<td>varies*</td>
</tr>
<tr>
<td>Crew</td>
<td>5</td>
</tr>
<tr>
<td>Scientific Party</td>
<td>10</td>
</tr>
<tr>
<td>Total Distance Towed</td>
<td>0</td>
</tr>
<tr>
<td>Operating Days</td>
<td>0</td>
</tr>
</tbody>
</table>

*Depends on towing vessel.*
**FINANCIAL SUPPORT**

Private gifts and grants to Scripps provided important support for a variety of programs during the past year. As Scripps prepares for its next century of discovery, philanthropy will play an increasingly critical role in funding research and education programs.

Hundreds of individuals and numerous foundations and corporations donated $3.8 million during fiscal 1994-1995. Private gifts and grants are vitally important because they provide key funding often not available from other sources. Community support creates endowments to finance outstanding research, fellowships for promising students and young scientists, and seed funding to spur the development of new ideas.

The 1994-1995 donors are named on the following pages. Below a few of this year's gifts are highlighted.

- The G. Unger Vetlesen Foundation, which supports global change research at some of the world's leading research institutions, has helped fund global change research at Scripps for the seventh year with a $500,000 grant.
- The ARCS Foundation provides funding for graduate fellowships in science, engineering, and medicine. Scripps is fortunate to receive support from two chapters of the ARCS Foundation, San Diego and Los Angeles. Over the past thirty years, the Los Angeles chapter of ARCS has given over $435,000 for ARCS Scholars at Scripps. The San Diego Chapter of ARCS, established in 1987, has awarded $65,000 for ARCS Scholars at Scripps.
- Dr. Cecil Green and his late wife Ida were steadfast supporters of Scripps for many years. Dr. Green continues his support of projects at the Cecil H. and Ida M. Green Institute of Geophysics and Planetary Physics at Scripps through the Cecil and Ida Green Foundation for Earth Sciences, which has provided over $380,000 in 1994-1995.
- Members of the E. W. Scripps Associates, the institution's premier annual support group, contributed more than $150,000 to various projects at Scripps last year. These gifts were given in addition to regular annual dues of $1,000. Members and the major projects they supported include Dorothy Deyo Munro, the aquarium's seahorse breeding program; Stephen and Marjorie Cushman, a boat for use by the Ocean Engineering Research Group; Ignacio and Brigitte Felix Cota, the aquarium nursery; Charlie and Mary Louise Robins, innovative research endowment; Alex and Diane Szekely, the aquarium's coral propagation project; and Alan and Nora Jaffe, a graduate fellowship. E. W. Scripps Associates funds also established a fellowship for a young investigator in the Climate Research Division.
- The family of Dr. Allen Peterson donated a 30-foot sloop valued at $48,000 to Scripps in his memory. Dr. Peterson, a Stanford faculty member, had many friends and colleagues at Scripps.
- The Scripps family continued their valuable support during the year. Robert Scripps gave $50,000 to underwrite programs at the aquarium. Sam Scripps pledged $104,000 in matching funds that enabled the marine biomedicine program to secure a grant of $200,000 from the National Science Foundation for a nuclear magnetic resonance spectrometer. This device enables researchers to determine the structure of compounds being studied for possible uses against cancer, arthritis, and other diseases.
- The Charles and Anna Stern Foundation awarded a grant of more than $42,000 to support basic research in the development of treatments for arthritis and other inflammatory diseases.
• The Burnside Charitable Foundation provided over $55,000 to the Center for Marine Biotechnology and Biomedicine (CMBB). These funds will support a molecular biology laboratory at CMBB and help train a student in marine molecular biology.

• The SIO Associates program grew to approximately 1,000 members. Gifts from Pier Group membership supported exhibit and educational programs and the aquarium-museum. These gifts financed a scholarship fund to encourage school groups from Baja California to visit the aquarium-museum, enhancing Scripps's role as a regional science education facility.

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**Agency** | **Expenditures for 93/94** | **Percent of Total** | **Expenditures for 94/95** | **Percent of Total**
--- | --- | --- | --- | ---
**Federal Government** | | | | 
National Science Foundation | $22,006,689 | 22.98 | $23,130,799 | 23.14
Defense, Department of | $14,107,346 | 14.73 | $12,420,827 | 12.43
Navy, Department of the | $14,103,492 | 14.73 | $12,385,476 | 12.39
Commerce, Department of | $7,234,326 | 7.55 | $7,800,596 | 7.80
Health and Human Services, Department of | $1,418,059 | 1.48 | $6,913,466 | 6.92
National Aeronautics and Space Administration | $4,247,603 | 4.44 | $4,214,791 | 4.22
Interior, Department of the | $2,436,488 | 2.55 | $1,617,600 | 1.62
Energy, Department of | $1,459,318 | 1.52 | $1,503,401 | 1.50
Other/Including Federal Flowthru Funds | $8,076,251 | 8.43 | $8,706,694 | 8.71
**Total Federal Government** | **$75,091,572** | **78.42** | **$78,693,650** | **78.74**
**Other** | | | | 
State General Funds | $14,138,480 | 14.76 | $15,199,587 | 15.21
Private Gifts and Grants | $1,900,357 | 1.98 | $2,831,823 | 2.83
Overhead Funds | $1,828,400 | 1.91 | $1,474,998 | 1.48
State of California | $1,501,602 | 1.57 | $1,626,898 | 1.63
Endowment Funds | $659,323 | 0.69 | $254,981 | 0.26
University Funds | $0 | 0.00 | $211,946 | 0.21
Local Government | $145,250 | 0.15 | $100,822 | 0.10
Sales and Services | $408,001 | 0.43 | (309,055) | -0.31
Reserves | $65,719 | 0.09 | ($138,174) | -0.14
**Total Current Funds Expenditures** | **$95,758,702** | **100.00** | **$99,947,477** | **100.00**

*Includes Overhead*
DR. MIRIAM KASTNER INSTRUCTS GRADUATE STUDENTS.
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Received a Young Investigator Award from the Office of Naval Research.

WALTER F. HEILIGENBERG
Honored with a special posthumous Faculty Excellence Award from UC San Diego.

T. GUY MASTERS
Elected Fellow of the American Geological Union.

JOHN W. MILES
Named as Fellow of the American Association for the Advancement of Science.

JOHN A. ORCUTT
Awarded the 1994 Maurice Ewing Medal from the United States Navy and the American Geophysical Union.

JASON PHIPPS-MORGAN
Awarded the James B. Macelwayne Medal from the American Geophysical Union.

VEERABHADRAN RAMANATHAN
Received the Buys Ballot Medal from the Royal Netherlands Academy of Sciences.
Elected a Fellow of the American Academy of Arts and Sciences.

JAMES R. STEWART
Honored with the 1994 Merrill P. Spencer Lifetime Achievement Award of the Undersea and Hyperbaric Society, Pacific Chapter.

VICTOR VACQUIER
Awarded the Alexander Agassiz Medal by the National Academy of Sciences.

PUBLICATION HONORED
The exhibition catalogue from the Stephen Birch Aquarium-Museum’s temporary, antique toy exhibit, Waves in Toyland, was included in Communication Arts Design Annual 35—one of the most prestigious publications in the graphic design business. Contributing staff included Leah Hewitt, designer; Joe Hlebica, writer, Susan Green, photographer; and Wendelin Montciel, museum curator.

SIO VIDEO UNIT
Chuck Colgan and William Call were awarded First Prize for Best Video in the 2nd International Videoeiras Video Festival in Oeiras, Portugal, for the video production Blue Planet Theater.
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. The bibliography of the Scripps Institution of Oceanography Contributions for years 1982 through 1984 is now on the World Wide Web. Searches can be conducted either by author or subject. Go to: http://orpheus.ucsd.edu/cgi-bin/sio/sio.search.pl

**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 46-year history are published irregularly in the *California Cooperative Oceanic Fisheries Investigations Atlas series*. Data reports, containing the processed data from specific cruises carried out under CalCOFI sponsorship, are published irregularly in the SIO Reference Series and in the CalCOFI data report series. To obtain copies of any of these CalCOFI publications, write to University of California San Diego Scripps Institution of Oceanography 9500 Gilman Drive Dept 0227 La Jolla CA 92039-0227.

**CalCOFI Publications**

**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 CA 94720.

The most recent volumes are listed below.


**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 advanced educational institutions. For exchange information please write to University of California San Diego Scripps Institution of Oceanography Library Exchange 9500 Gilman Drive Dept 0175-C La Jolla CA 92039-0175.

The articles listed below were published in the 1994 volume and may also be found in the publications cited. Information about a specific reprint can be obtained by writing directly to the Scripps author in care of University of California San Diego Scripps Institution of Oceanography 9500 Gilman Drive La Jolla CA 92039.


Other Works


Naga Report Series

The Naga Report series covers the scientific results of marine investigations in the South China Sea and the Gulf of Thailand from 1959 through 1961. For a list of available reports and costs, please send inquiries to University of California San Diego Scripps Institution of Oceanography Naga Reports 9500 Gilman Drive Dept 0201 La Jolla CA 92039-0201.

Publications for Members of the Stephen Birch Aquarium-Museum


Scripps Institution of Oceanography Reference Series

The reference series includes data reports, preliminary research reports, historical reports, and contractual reports distributed mainly under government contracts. There is no mailing list for this series. For inquiries about the Scripps Institution of Oceanography Reference Series and requests for free copies of the starred edition, please write to University of California San Diego Scripps Institution of Oceanography Technical Publications 9500 Gilman Drive Dept 0233-B La Jolla, California 92039-0233.

Reference numbers listed were issued in 1994.


94-2 Canceled


94-7 Canceled

Global Discoveries for Tomorrow's World

Sea Grant Publications
The publications listed below unless otherwise stated can be obtained by writing to University of California San Diego California Sea Grant College 9500 Gilman Drive Dept 0232 La Jolla CA 92039-0232.

Education Series

Reference Series

Technical Series

Marine Extension Publications
Copies of Marine Extension publications can be obtained by writing to University of California Davis Sea Grant Extension Davis CA 95616.
### Graduate Department
- **Chairman**
  - Richard H. Rosenblatt
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  - Applied Ocean Sciences
  - William S. Hodglass
  - Biological Oceanography
  - Peter J. Franks
  - Climate Sciences
  - Richard C. J. Somerville
  - Geochemistry and Marine Chemistry
  - Ray F. Weiss
  - Geological Sciences
  - James W. Hawkins
  - Geophysics
  - Duncan C. Agnew
  - Marine Biology
  - Ronald S. Burton
  - Physical Oceanography
  - William R. Young
- **Undergraduate Coordinator**
  - Earth Sciences
  - Jean-Bernard H. Minster
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  - Ship Operations and Marine Technical Support
  - Robert A. Knox
  - Nimitz Marine Facility
  - Thomas S. Althouse
  - Shipboard Technical Support Services
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    - James H. Swift, Scientific advisor
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  - Robert C. Wilson
  - Shipboard Computer Group
  - Ronald L. Moe
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  - Perry J. S. Crampton
  - Oceanographic Data Facility
  - James H. Swift
  - Geological Data Center
  - Stuart M. Smith
- **Scientific Collections**
  - Benthic Invertebrates
  - William A. Newman
  - Geological
  - William R. Riedel
  - Marine Vertebrates
  - Richard H. Rosenblatt
  - Planktonic Invertebrates
  - Mark D. Ohman

### Administration
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- **Geosciences Research Division**
  - Wolfgang H. Berger
- **Marine Biology Research Division**
  - Jeffrey B. Graham
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  - William H. Fenical
- **Physical Oceanography Research Division**
  - Nan A. Bray

### Research Units
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  - Robert T. Guza
- **Center for Marine Biotechnology and Biomedicine**
  - Jeffrey B. Graham (Acting)
- **Marine Life Research Group**
  - Michael M. Mullin
- **Marine Physical Laboratory**
  - William A. Kuperman

### Special Programs
- **California Environmental Technology Center**
  - Al Alm
- **Center for Clouds, Chemistry and Climate**
  - Veerabhadran Ramanathan
- **Joint Institute for Marine Observations**
  - Warren B. White
- **Sea Grant College Program**
  - James J. Sullivan

### Affinity Group
- **Neurobiology Unit**
  - Theodore H. Bullock

### UC Institutes
- **CalSpace Institute**
  - Sally K. Ride
- **Institute of Geophysics and Planetary Physics**
  - John A. Orcutt, Assoc. Dir.
- **Cecil and Ida Green Pitzer Field Observatory**
  - Frank K. Wyatt

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IN MEMORIAM

ROBERT SIPLE ARTHUR
June 1995
Bob Arthur, emeritus professor at Scripps, retired from the institution in 1979. He received his doctorate at Scripps in 1950 and was appointed to the faculty the following year. He taught and published on many aspects of physical oceanography, including tsunamis, currents, and ocean temperature.

ALAN BRATKOVICH
January 1995
Alan Bratkovich received his Ph.D. from Scripps in 1981. He was an oceanographer at the National Oceanic and Atmospheric Administration’s Great Lakes Environmental Research Laboratory, and an adjunct professor at the University of Michigan, Ann Arbor.

ROBERT S. DIETZ
May 1995
Robert Dietz first came to Scripps in the 1930s to work for Francis Shepard as a technician. He received his Ph.D. from Scripps in 1941 and worked briefly for the UC Division of War Research.

PATRICIA DOYLE
June 1995
Pat Doyle was a paleontological specialist at Scripps from 1972 until 1992. Her work uncovered the importance of using microscopic fish teeth and scales found in deep-sea sediments to interpret sequences of pelagic clays.

ALBERT EDWARD JOHN ENGEL
March 1995
Arriving at Scripps in 1958, Albert Engel was an early research geologist and professor of geology at the institution whose work added greatly to the understanding of the makeup of the ocean crust. He was an active teacher at the undergraduate and graduate levels. He retired in 1987.

WALTER F. HEILIGENBERG
September 1994
Walter Heiligenberg, professor of behavioral physiology, joined Scripps in 1973 and was a leading expert on the electric senses of certain fishes. His work added significantly to the understanding of how neurological systems process information and how the brain controls behavior.

JAMES R. MORAINTY III
April 1995
James Moriarty III worked at Scripps from 1952 until 1968 as an illustrator and cartographer, primarily for Francis Shepard. With Carl Hubbs and George Shumway, he published research on an early archeological site in Scripps Estates, near the Scripps campus.

KENNETH M. PLUMMER
October 1994
Ken Plummer, a 15-year UC employee, served as a staff research associate with Scripps’s Marine Life Research Group, working both in the laboratory and at sea. He assisted with the analysis of physical and biological data for the CalCOFI program and for biological oceanographer Tom Hayward.

RUSSELL W. RAITT
March 1995
Russ Raitt, professor emeritus of geophysics, was affiliated for more than 50 years with Scripps. He was a pioneer in geophysical measurements at sea and helped define the structure and evolution of the deep ocean bottom. He was a key participant in ocean surveys in the 1950s and 1960s that were central to development of the theories of seafloor spreading and plate tectonics.

GARY REYNOLDS
May 1995
Gary Reynolds, retired from Scripps in 1991, spent 23 of his 25 years at UC San Diego working in Scripps’s Refrigeration Shop.

HENRY RUMBLE
January 1995
Captain Henry Rumble, USN retired, was involved with the engineering design activities of Scripps’s Marine Physical Laboratory from 1970 to 1984.

JAMES M. SNODGRASS
November 1994
James Snodgrass, retired from Scripps in 1974, headed the Special Developments Division for many years. He played a significant role in the introduction of satellite navigation into oceanography and the development of the expendable bathythermograph.

DANA “SKIP” SYMONDS
April 1995
Dana “Skip” Symonds, a retired chief engineer, worked at Scripps from 1968 until 1979, sailing on numerous Scripps research ships. After retiring, he worked at Scripps’s Nimitz Marine Facility as a part-time security officer.

THOMAS J. WALSH
February 1995
Tom Walsh worked at Scripps from 1962 until his retirement in 1988 as assistant curator of the Scripps Geological Collections. He participated in many cruises and worked on the precursor to the Deep Sea Drilling Project.

PETER M. WILLIAMS
December 1994
Pete Williams, a research chemist with Scripps’s Marine Research Division, received his Ph.D. at Scripps in 1960 and was a founding member of the Food Chain Research Group in 1963. His research interests included the chemical nature of dissolved and colloidal organic carbon in the oceans.