UCSD

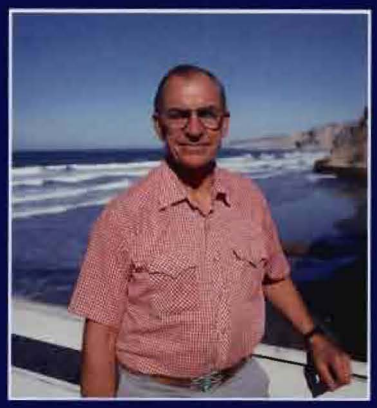
SCRIPPS INSTITUTION OF OCEANOGRAPHY

1990

ANNUAL REPORT

D E D I C A T I O N

EQUALLY AT HOME at a workbench, a desktop, or aboard ship, Victor C. Anderson applies his mastery of electronics and physics to a wide range of underwater problems. His creativity has resulted in novel ocean instruments, remotely controlled sea-floor vehicles, and new techniques in acoustic signal processing and ocean engineering.



Anderson's fascination with electronics goes back to his childhood in China when his missionary parents gave him an electricity kit, and later, a radio. Things involving electricity come naturally to him, in fact, he only took one college course in electronics. After completing his undergraduate physics degree at the University of Redlands in 1943, Anderson joined UC Berkeley's Lawrence Radiation Laboratory to work on the Manhattan Project. In 1946, he enrolled as a graduate student in physics at UCLA, and the following year, he joined the newly formed Marine Physical Laboratory at Scripps where he studied the deep scattering layer to complete his doctoral degree in 1953.

While conducting post-doctoral work at the Acoustics Research Laboratory at Harvard University, Anderson began to develop a digital time compression technique for application to acoustic signal processing. In 1955, he returned to MPL to continue research in underwater sound and ocean engineering. He developed a digital multibeam steering system, DIMUS, which is still used in oceanography and on surface ships and U.S. Navy submarines. He designed and built a series of remote underwater manipulators, known as RUMs, which can be placed on the ocean bottom to observe specific features at close range and collect rock samples or sediment cores.

In 1968, Anderson became a professor at Muir College with a parallel appointment as deputy director of MPL. He has twice served as department chairman of the Department of Electrical Engineering and Computer Sciences and has participated in the joint UCSD-SIO applied ocean science program since its inception.

Anderson was honored for his role in underwater acoustics and ocean engineering by his election as a Fellow of the Acoustical Society of America and by the Navy's highest civilian award, the Distinguished Public Service Award. He holds a half-dozen patents and has worked on many development projects for devices such as Deep Tow, the infrasonic Swallow float array, TV/sonar imaging systems, and others for the navy's undersea missions. Quite simply, Anderson says, it is fun to solve problems and develop new hardware and instrumentation.

Although retired, Victor Anderson continues his teaching and research. He and his wife Anne are at home on their horse ranch in Alpine and are known in both the university and the community for their quiet support.

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1990 ANNUAL REPORT

UNIVERSITY OF CALIFORNIA, SAN DIEGO

This is the University of California, San Diego, Scripps Institution of Oceanography Annual Report 1990 (for the year ending June 30, 1990). ISSN 1046-9443. A major portion of the work reported herein was supported by the National Science Foundation and the Department of the Navy. For more information on the institution please write: University of California, San Diego, Scripps Institution of Oceanography, Technical Publications 0233-B, 9500 Gilman Drive, La Jolla, California 92093-0233.

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INTRODUCTION

THE PAST YEAR has seen momentous changes on the world scene and in our nation's prospects for the future. Changing geopolitical structures, a new focus on education, a further awakening of environmental consciousness, economic competition in the international arena, and an emerging debate on energy and resources are all issues that have come to the fore. These, in addition to the current economic downturn, play a direct role in the daily life of our institution.

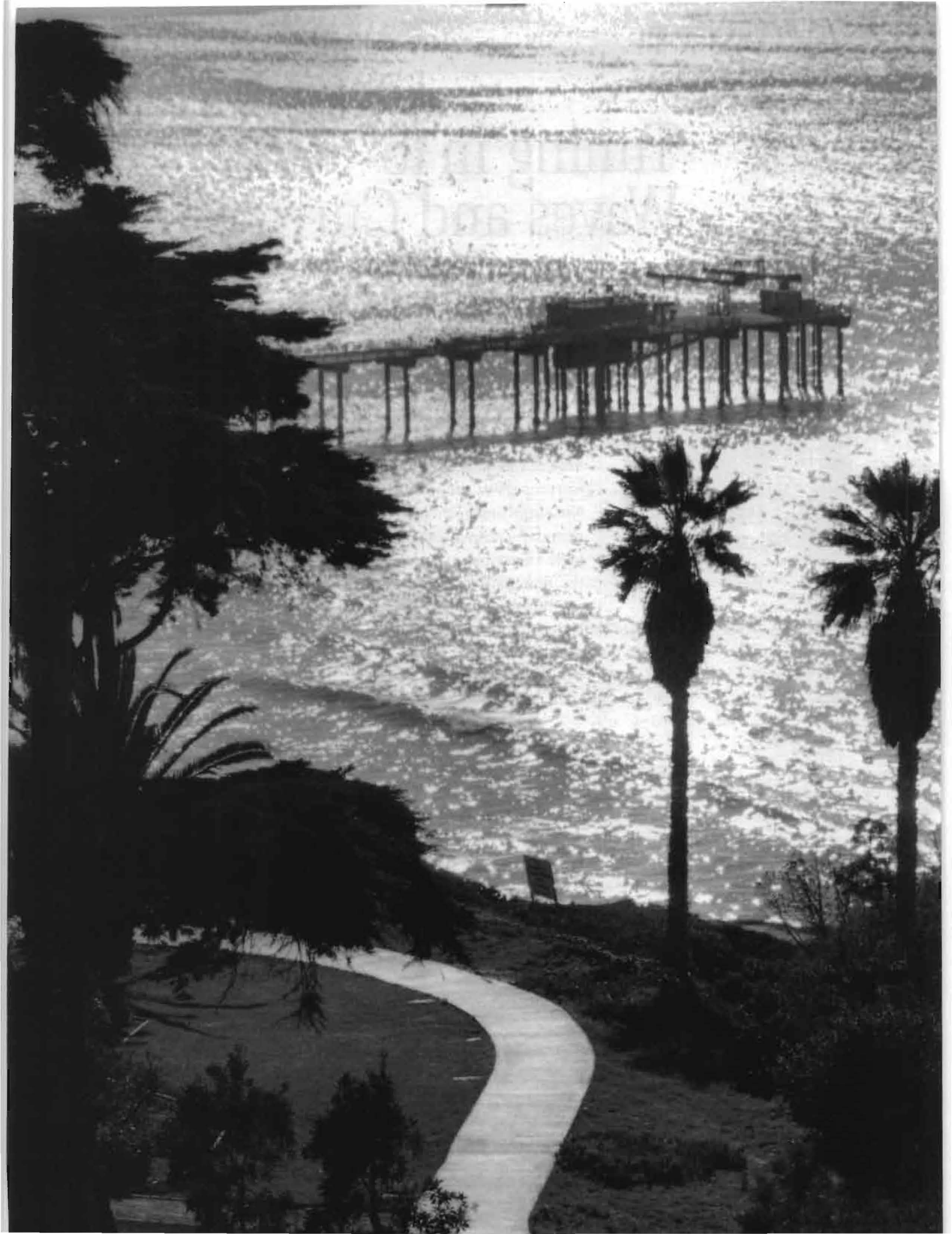
It is often not understood that changing national and state policies have an almost immediate and direct effect on the day-to-day operations of a research and teaching institution such as ours. Changes in national priorities are directly reflected in the areas the federal government chooses to support most heavily in the budget process. On the state level, the economic downturn translates both into a direct loss of employment and severe decreases in support of research and teaching activities.

The course of action we have been pursuing in response to these various pressures is a combination of prudence and boldness. Scripps has been on a most active and successful recruiting campaign to set the stage for the early years of the next century. We are striding forth boldly in some areas of national importance, such as global change, but in others we are continuing to maintain a presence even though the federal support is weaker, in the firm belief that they are of true scientific interest and benefit. I believe that if we can maintain our momentum in these matters, we can be flexible and innovative in our scientific pursuits while steadfastly pursuing our goal of understanding the world's oceans, their basins, and the atmosphere above.

Specifically, the importance of the oceans in the changing nature of the world is slowly becoming a more widely recognized aspect of public policy. The oceans are a sink for the ubiquitous emissions of carbon dioxide gas. Of the billions of tons released by man in a year, they absorb about half. Their capacity to continue in this role, and the fate and further cycling of these gases are fundamental questions in understanding global warming and other aspects of global change. Issues of marine biodiversity, the ecology of the food chain on very large scales, and the effects of environmental degradation to the health of, and enjoyment by, people have become increasingly important issues. Moreover, the floor of the oceans contains the majority of the world's mineral and energy resources. Eventually satisfying society's needs in this regard will depend upon understanding local ocean currents and circulation patterns if safe retrieval and recovery is to be possible. Coastal oceanography promises to grow into a burgeoning field based on a multitude of concerns for the environment, food, natural resources, and national security.

Scripps has many needs today, such as funds for helping young scientists launch their careers, new laboratory facilities, building renovations, and for support of graduate students. While we have had some success with federal funding in a few areas, we are in the process of putting into place a more vigorous development program with foundations and private donors. I believe that our role and mission is becoming even more important to society than in the past. Innovation, drive, and scientific excellence will provide the necessary momentum to sustain our leadership role into the 21st century. The Scripps staff, faculty, and students have performed admirably in these tight times. With their help and understanding we will emerge even stronger.

Edward A. Frieman, Director
March 1991



Tuning in to Waves and Currents

by Jerome A. Smith

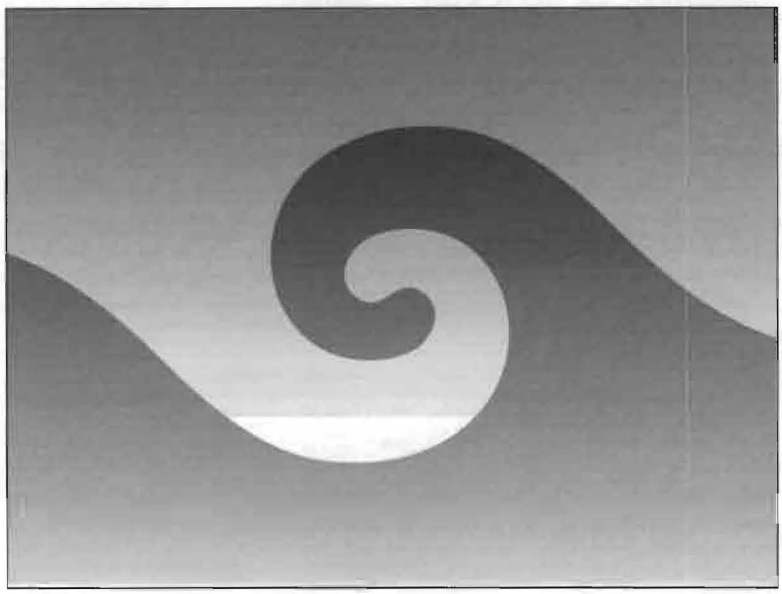
Dr. Jerome A. Smith checks the pressure case on a Doppler sonar.

THE OCEAN IS FULL OF WAVES, and not just at the surface. Water near the surface is less dense than the water below: if a blob of water were dragged downward, it would float back up, overshoot slightly, and sink back down, oscillating for a while. Thus "stratification" allows the existence of waves. Unlike surface waves, these "internal waves" can propagate upward and downward, as well as horizontally. Not surprisingly, such internal waves are ubiquitous in the oceans. As various waves intersect in the interior of the ocean, there are regions of stronger and weaker flows. Occasionally, the flow pattern can put denser water over lighter water, resulting in strong mixing. Such a mechanism is thought to be important in the long-term mixing of the oceans. But how can one hope to measure these waves? The largest vertical scales are comparable to the total water depth (4-6 km), while the scales of these "overturning events" are probably closer to 1 m. Thus, a tremendous array of current meters would be needed.

Twenty years ago Dr. Robert Pinkel found a way to "break the measurement barrier" for internal waves in the ocean. He used two complementary approaches. The first method involved a CTD, which measures conductivity, temperature, and depth, and hence the density versus depth. A CTD can profile rapidly and often (completing a 300 m profile every 3 minutes). The other method, based on Doppler shifting of 75 kHz sound reflected from the interior of the sea, was more of a gamble. Although Doppler-shift measurements with radar and sonar had been used successfully in the atmosphere, it wasn't clear that a similar approach would work in the ocean. Happily, it did, and the Doppler sonar yielded velocity measurements over nearly a kilometer in depth.

How does a Doppler sonar work? Sound is scattered by small particles in the ocean and the reflected tone is shifted in frequency by an amount proportional to the velocity toward or away from the instrument. Using timed pulses of known frequency, velocity is measured as a function of range, to a distance limited by attenuation and spreading of the sound in the water. In addition, the intensity of the returning sound is related to the density of the particles and thus reveals much about populations of plankton or bubbles. For each sonar system there is a tradeoff; a longer pulse of sound

Dr. Smith, Eric T. Slater, Lloyd L. Green, and Michael A. Goldin test the impedance of a 195-kHz transducer.



S. Cook

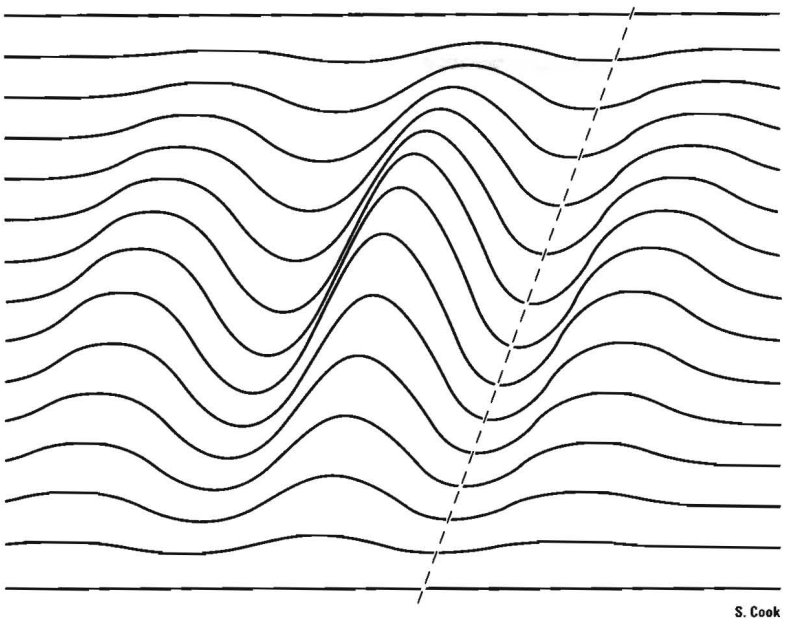
The upper (lighter) portion of this internal wave represents lighter fluid. The darker portion shows denser fluid. When an internal wave "breaks" this symmetric "rolling" is thought to occur, followed by rapid mixing.

allows a better estimate of frequency and hence less error in velocity. However, this corresponds to an average over a longer range interval. This creates an uncertainty principle for Doppler sonars; the product of range-resolution times velocity error is inversely proportional to the sonar frequency. Unfortunately, high frequency sound is attenuated rapidly in the oceans (200 kHz sound is usable only to about 400 m away, while 75 kHz sound can reach to 1.5 km).

The ocean moves at all scales. The smaller the scale, the weaker the velocities. As a result, each sonar has a small-scale limit, where the range resolution needed times the strength of the currents are near the values set by the sonar frequency. The smaller scale motions, with smaller velocities, are either filtered out by the range averaging or hopelessly buried in the noise. To investigate a wide range of scales of motion requires a variety of systems. Lower frequency sonar systems reach farther in range and define the larger scales of motion, while the shorter-range high frequency systems have the resolution and precision to "see" smaller scales of interest. In earlier work, the 75 kHz Doppler sonars provided the large scales, while small scale motions were inferred from CTD data.

Recently, a higher frequency system (160 kHz) was developed to measure velocities on scales down to a meter or so, nearly to the scale of the overturns themselves. The results of this work are dramatic. Briefly, when viewed in a fixed frame, the internal wave spectra differ markedly from the previous semi-empirical models. This is true especially at the smaller scales. (The smaller scale activity is significantly flatter in frequency than the model.) However, when viewed in coordinates that move vertically with the water, the resulting spectra are fairly close to the idealized model. The implication is that the smaller waves are carried passively up and down by the larger ones, with little net transfer of action (over a complete cycle), and that the "intrinsic" spectrum is indeed similar to the simple model.

Another burgeoning field of application for Doppler sonars is the study of surface waves and their interaction with surface currents. Although surface waves have been studied extensively for about a hundred years, many aspects of their generation, evolution, and decay in the natural environment are poorly understood. This is undoubtedly because of the difficulty of obtaining measurements. The events of most interest are the times of strongest generation: during storms. Yet, who wants to be out in the middle of the ocean during a storm? Collection of detailed, sensible data under such circumstances clearly presents a dilemma. The combination of Doppler sonar technology and Scripps's Floating Instrument Platform (FLIP) provides a unique solution. FLIP has both the electric power and the stability needed to operate a variety of sonar systems (in winds up to about 40 knots), and can be deployed well out to sea. A recent major experiment was carried out in the Pacific to clarify wave growth and breaking, and the resultant influ-



S. Cook

The undulating lines on the diagram represent the motions in time of parcels of water, as an internal wave "packet" passes. The intersecting dotted line shows the vertical propagation of the waves.

ence on the surface layer of the sea. To obtain directional wave measurements, a new sonar system with fan-shaped beams was developed. The beams are broad in the vertical plane, and intersect the surface over several hundred meters. The near-surface bubble layer is acoustically much brighter than below, so the velocity estimates correspond to lines along the ocean surface, and are relatively insensitive to rolling or pitching. The frequency chosen (200 kHz) allows resolution of surface waves down to 6-m wavelength (2 second period), with coverage to nearly 400 m. A 75 kHz sonar was also modified for surface scanning, providing 12-m resolution over roughly a kilometer in each direction from FLIP. Several storm systems were experienced, and excellent wind, wave, and current data were obtained.

Doppler sonars are also being used in nearshore research. A prototype sensor (developed at the Center for Coastal Studies) sits on the ocean bottom and measures velocities at 4 points around a 1.5 m diameter circle on a horizontal plane. This set-up provides results for directional spectra that compare well with results from pressure sensors. Another nearshore prototype may clarify the interaction of waves and nearshore flows such as rip currents, edge waves, and river plumes.

As more techniques and technology are becoming available, we can look forward to new applications for Doppler sonar technology, and the prospect of learning about heretofore unapproachable phenomena.

Suggested Reading:

Pinkel, R. Doppler sonar measurements of ocean waves and currents. *Marine Technology Society Journal,* v.20, 1986. pp.58-67.

Pinkel, R., A. Plueddemann, and R. Williams. Internal wave observations from FLIP in MILDEX. *Journal of Physical Oceanography,* v.17, 1987. pp.1737-1757.

Pinkel, R., and J. A. Smith. Open ocean surface wave measurement using Doppler sonar. *Journal of Geophysical Research,* v.92, 1987. pp.12,967-12,973.

Smith, J., R. Pinkel, and R. A. Weller. Velocity structure in the mixed layer during MILDEX. *Journal of Physical Oceanography,* v.17, 1987. pp.425-439.

Electromagnetic Exploration of the Ocean and Sea Floor

by Douglas S. Luther

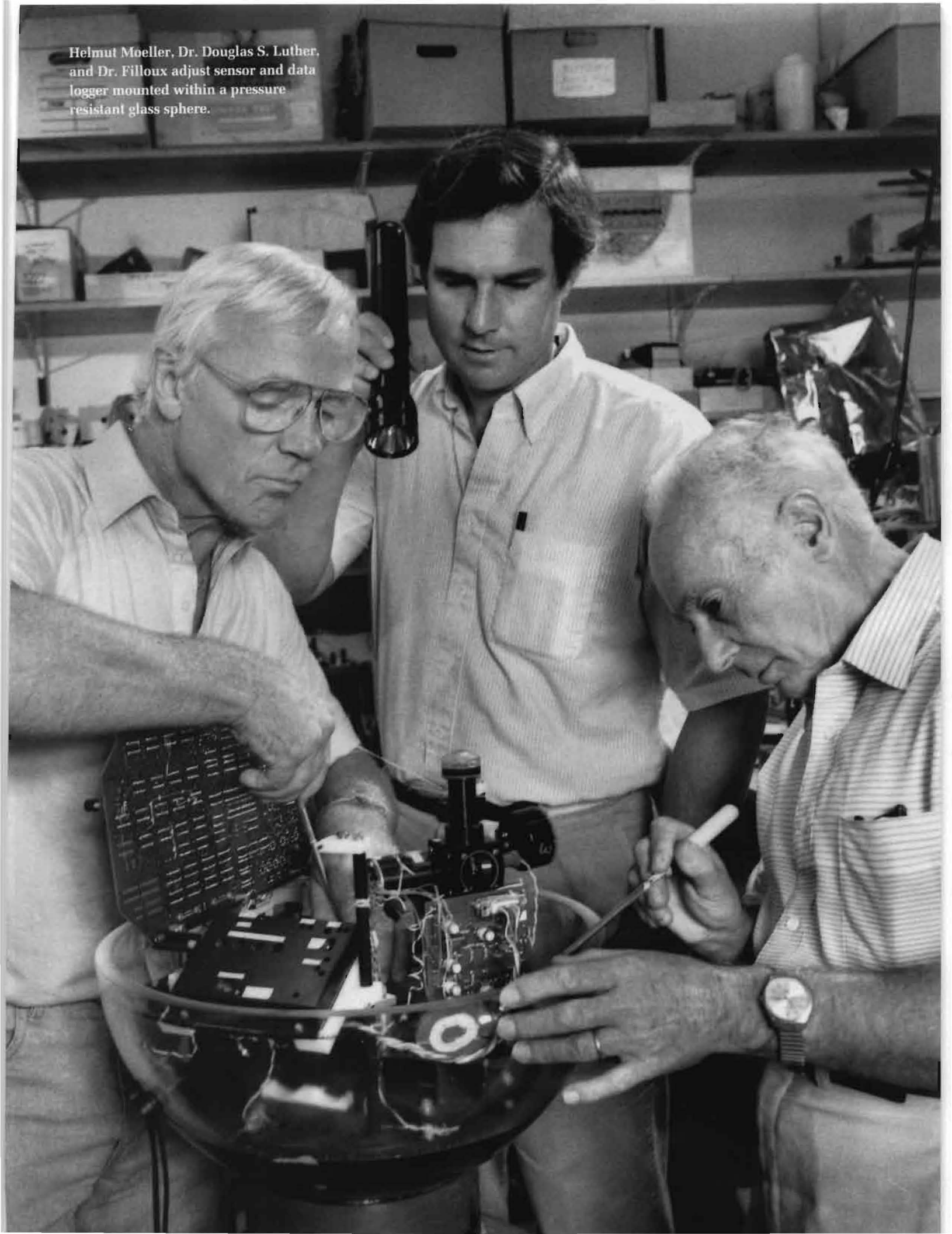
Dr. Jean H. Filloux checks out a sea-floor recorder prior to deployment.

THE OCEAN, LIKE THE ATMOSPHERE AROUND US, is replete with electromagnetic fields. These range from the very short period signals we call light to long period signals associated with the movement of saltwater (a conductor) through earth's permanent magnetic field. As long ago as 1832, Michael Faraday suggested that observing low frequency electric fields in the ocean would be an excellent way to measure the motion of the surrounding water. Unfortunately, Faraday was unsuccessful in his attempts.

One hundred and fifty years later, scientists can observe electric and magnetic fields in the ocean. And they have perfected the theory explaining how these observations relate to both water motion and electrical properties (such as conductivity) of the ocean and earth.

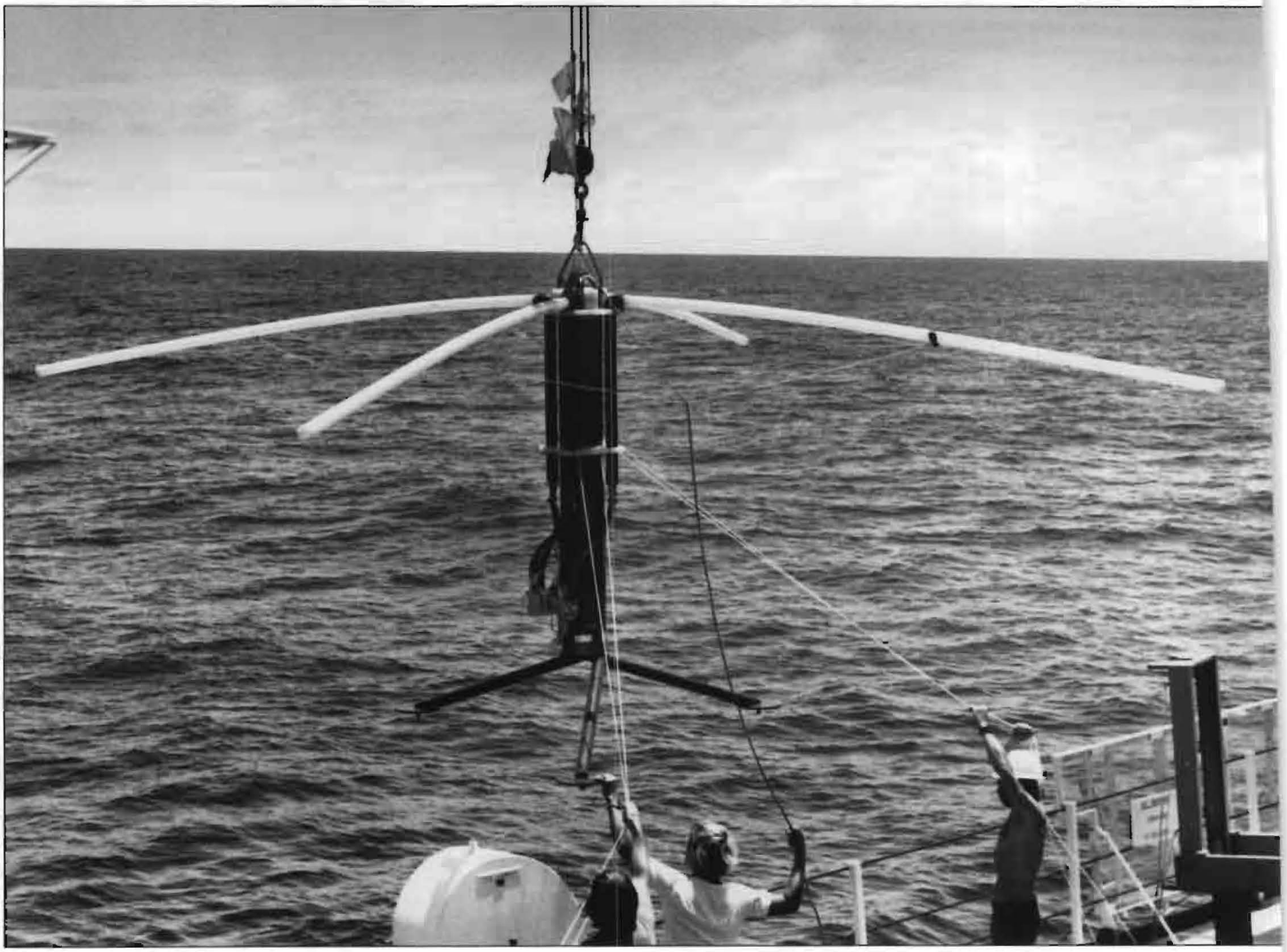
The use of electromagnetic fields to study both water motion and earth structure derives from the propagation characteristics of electromagnetic signals in the (conducting) ocean and (less-conducting) earth. At periods greater than a few minutes, electromagnetic signals generated by fluctuations in the outer portions of earth's atmosphere, the ionosphere and magnetosphere, can penetrate the conducting ocean and propagate into the earth. The longer the period is, the deeper the penetration into the earth. At the water-earth boundary, the relative strengths of these electric and magnetic signals as a function of period are directly related to the conductivity of the underlying rocks at moderate depths; typically, from 50 km on down to several hundred kilometers. Conductivity in this region is related to temperature and the fraction of the rock that is actually in a liquid state. These are important parameters in models of the structural evolution of the earth's lithosphere.

At the longest observable periods–beyond a few days–the electric signals in the ocean are dominated by the fields generated by the dynamo effect of the conducting saltwater moving through earth's stationary and permanent magnetic field. A definitive mid-ocean corroboration of this effect has been obtained by Scripps scientists. The Physical Oceanography Research Division section of this report has an example of what such signals reveal about the ocean.



Helmut Moeller, Dr. Douglas S. Luther, and Dr. Filloux adjust sensor and data logger mounted within a pressure resistant glass sphere.

A sea-floor instrument is lowered over the side. For up to two years it will record the ambient electric field over the distances spanned by the plastic pipes at the top.



J. Filloux

Deep ocean magnetotelluric sounding–a method of exploring the conductivity structure of the lithosphere with sea-floor measurements of ambient electric and magnetic fields at periods of minutes to a few days–was pioneered at Scripps. This work has yielded the only information available on the deep electrical structure of the ocean basins. In recent work, linear arrays of instruments were oriented across major sea-floor topographic features associated with the interaction of the mobile crustal "plates." In the most extensive such experiment, the ElectroMagnetic Study of the Lithosphere and Beyond (EMSLAB), sea-floor and continental data were collected by investigators from the United States, Canada, Japan, and Australia. EMSLAB provided a complete electrical transect of the Juan de Fuca Plate off Oregon. Concrete evidence of subduction of the plate beneath Oregon was obtained by electrically imaging the conductive top of the down going plate. EMSLAB scientists also showed that a combination of land and sea-floor electromagnetic data is much more powerful than either type taken alone.

To measure the conductivity of oceanic lithosphere shallower than 50 km, shorter period signals are needed than naturally exist at the bottom of the ocean. The conducting seawater attenuates the short period signals generated in the upper atmosphere before they reach the sea floor. The short period signals can be replaced, in a sense, by using man-made electromagnetic sources. Developed at Scripps, this controlled source sounding employs an electromagnetic transmitter on the sea floor, which broadcasts electromagnetic energy into the

sea-floor rocks at periods of .05 to 10 seconds. The resultant electric field on the sea floor is measured at ranges of up to 100 km from the transmitter. Because the conductive water absorbs the transmitted energy, the signal can travel only through the less conductive rock, just as radio waves travel through the air and not metal. The measured attenuation of the electric field with distance from the transmitter is directly related to the conductivity structure of the underlying rock.

Two recent experiments suggest that at depths of 5 to 30 km the lithosphere is very resistive (non-conductive). This means that it is relatively cold and dry with at most 0.1% free water by volume. This is consistent with two significant concepts: first, that volatiles are removed at mid-ocean ridges during the manufacture of the oceanic lithosphere; and second, that the volatiles are not replaced by circulation between the upper lithosphere and the underlying deeper mantle. The discovery of such a highly resistive lithosphere explains why the long period (greater than a few days) electric fields in the ocean are so well related to the strength of the water motion. Specifically, the water-generated fields are not short-circuited by electric currents flowing through the lithosphere because the lithosphere is such a poor conductor.

These examples are but a few of the potential applications of electromagnetic measurements to studies of the ocean and its hidden sea floor. Drs. Charles S. Cox, Jean H. Filloux, Alan D. Chave, Douglas S. Luther, Steven C. Constable, and Spahr C. Webb continue to lead the field in demonstrating the utility of this technique. They are using it to extend our knowledge of the structure and movement of both ocean waters and the earth below.

Suggested Reading:

Chave, A. D., D. S. Luther, and J. H. Filloux. Spatially-averaged velocity from the sea-floor horizontal electric field. *Proceedings of the IEEE Fourth Working Conference on Current Measurements, Clinton, Maryland, April 3-5, 1990.* 1990. pp.46-53.

Constable, S. C. Marine electromagnetic induction studies. *Surveys in Geophysics,* v.11, 1990. pp.303-327.

Interaction between Molecular Biology and the Marine Sciences

by Douglas H. Bartlett

Dr. Douglas H. Bartlett extracts fluorescently labeled DNA after ultracentrifugation.

TO CLONE OR NOT TO CLONE? Today, more and more often biologists are answering this question in the affirmative. The burgeoning number of techniques in molecular biology is providing new applications to long-standing questions in such diverse areas as evolution, population dispersal, physiology, development, gene regulation, and structure/function analyses. At the Scripps Institution of Oceanography molecular tools are supplementing other experimental approaches in a number of laboratories; including those of Drs. Margo G. Haygood, Douglas H. Bartlett, and Victor D. Vacquier.

Researchers in Dr. Haygood's laboratory are interested in the relationship between free living and symbiotic luminous bacteria. Unlike many of the symbiotic bioluminescent bacteria, those associated with the light organs of flashlight fishes (family Anomalopidae) cannot be cultured in the laboratory. Because of this barrier, traditional bacterial taxonomy is impossible. However, Dr. Haygood circumvented this problem by isolating sufficient DNA from the symbiont of the Caribbean flashlight fish *Kryptophanaron alfredi* to prepare and propagate a gene library. Later the symbiont gene encoding the alpha subunit of the luciferase enzyme was identified, and its nucleotide sequence determined. By using the luciferase sequence as a measure of the relationship to other bioluminescent bacteria, laboratory researchers discovered that the *K. alfredi* symbiont is a previously uncharacterized bacterium of the genus *Vibrio*. Experiments are in progress to perform molecular taxonomy on symbionts of flashlight fish belonging to two additional fish genera. Researchers performed preliminary DNA:DNA hybridization experiments (referred to as Southern blotting) using luciferase and 16S rRNA DNA. This work revealed that the symbionts may have co-evolved with the host fish. The symbionts from different host genera differ greatly from one another, and symbionts from hosts of two different genera collected in the same area are no more similar to one another than to a symbiont from a third genus from another location.

The molecular techniques that are being used to compare bacteria are also used to compare higher marine organisms. Even when organismal DNA is present in only minute quantities, it is possible to amplify specific nucleotide sequences as a prelude to further molecular analysis. In col-

Graduate student Ellen Chi sets up a bacterial conjugation experiment in order to transfer recombinant DNA molecules into deep-sea bacteria.

Dr. Bartlett puts a tube of bacterial cell lysate into the centrifuge for DNA purification.

laboration with Dr. William F. Perrin, National Marine Fisheries Service, scientists in the Haygood laboratory use the polymerase chain reaction (PCR) to amplify harbor porpoise and common dolphin mitochondrial DNA to examine genetic relationships within and between these cetaceans.

Dr. Bartlett's group uses molecular biology to follow the processes by which deep-sea bacteria respond to changes in hydrostatic pressure. One deep-sea bacterium, SS9, responds to increasing pressures (up to 280 atmospheres) by producing increasing amounts of an outer membrane protein designated OmpH. The deduced amino acid sequence of this protein is similar to a class of bacterial proteins known as porins, which form diffusion channels in the cell membrane.

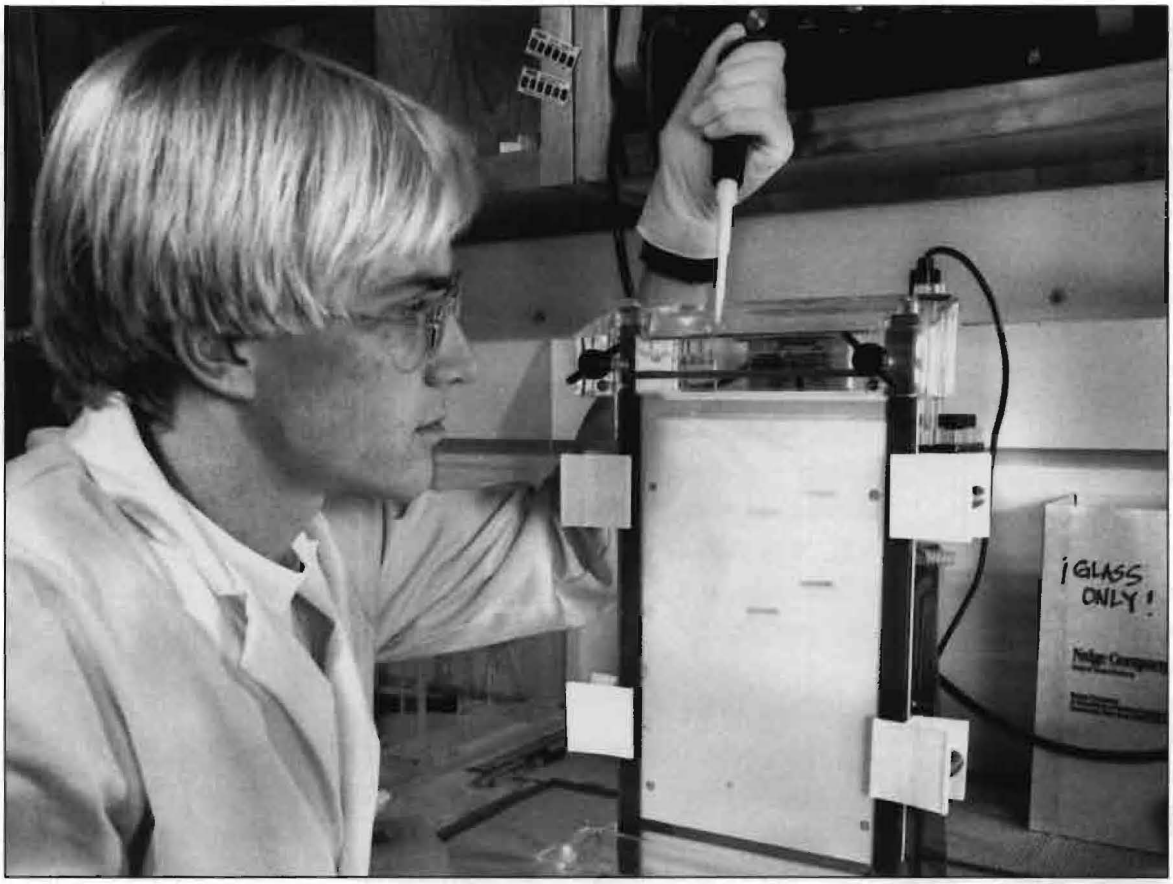
The cloned gene for this protein has been used to perform so called reverse genetic experiments. The gene has been mutated and transferred via conjugation back into the deep-sea bacterium, where the mutated gene was allowed to replace the wild type gene in the bacterial chromosome. Consistent with OmpH functioning as a porin, the OmpH-defective strain grows much more slowly under minimal nutrient conditions. Physiological comparisons between the mutated and wild type strain are in progress to determine the function of OmpH in pressure adaptation.

A second genetically engineered SS9 strain contains another mutation in which the gene is under the transcriptional control of a promoter, the activity of which is regulated by the amount of toluic acid present in the growth medium. This will allow Dr. Bartlett to manipulate OmpH production and correlate the abundance of this protein with the ability of the bacterium to adapt to high pressure.

Phenomena governing enzyme adaptation to high pressure in deep-sea bacteria are also being studied. In collaboration with other Scripps biologists, Dr. Bartlett's group has cloned and sequenced the gene encoding malate dehydrogenase (MDH) from SS9. While it is difficult to obtain sufficient MDH from SS9 for biochemical characterization, this problem has been overcome by cloning the *mdh* gene and overproducing the enzyme in the bacterium *Escherichia coli*. By comparing and manipulating sequences of MDHs from closely related bacteria, both pressure adapted and pressure unadapted, the structural constraints for enzyme function at high pressure will become known.

Dr. Vacquier's group is using molecular techniques to study marine invertebrate fertilization. Knowledge of the proteins and their genes, which mediate the species specific events of sperm-egg interaction, is important for understanding the molecular mechanisms of fertilization. The evolution of mechanisms that prevent sperm-egg interaction and create barriers to reproduction between different species are important biological problems. Abalone spermatozoa possess an acrosomal protein called lysin, which dissolves a hole in the outer egg envelope in a species specific manner by a non-enzymatic mechanism. Dr. Vacquier is interested in lysin function and is comparing the lysin protein sequences from various abalone species. The cDNAs for lysin have been cloned and sequenced from pink and red abalone. Predictions of secondary structure indicate both proteins possess homologous alpha helices. The first fifteen amino acids of lysin are hypervariable and may be subject to particularly rapid evolutionary change. Nucleotide sequences encoding four additional lysins (green, black, white, and flat abalone) have recently been obtained. Structural predictions of these proteins paint a similar picture. The amphiphilic nature of lysin may promote orientation of the protein's hy-

Timothy J. Welch in the electrophoresis laboratory. He is loading a DNA sequencing gel.



drophobic helical surfaces toward one another until contact with the egg envelope is made. The alpha helices may then rotate allowing the hydrophobic portion of the protein surface to compete for binding to the nonpolar components that hold the egg envelope fibers together.

In collaboration with the Scripps Institutions of Science and Medicine, the three dimensional crystal structure of lysin is being solved and will provide an unambiguous description of lysin structure. Abalone sperm lysins are being studied to clarify their function. They may also be useful markers for studying evolutionary change among abalone species distributed worldwide.

Many exciting questions remain. For example, is lysin expressed in other abalone tissues, and if so, for what additional functions? Lysin research is providing both cell biologists and molecular biologists clues to a novel mechanism used by one cell to penetrate the extracellular matrix of another.

Suggested Reading:

Bartlett, D. H., M. Wright, A. A. Yayanos, and M. Silverman. Isolation of a gene regulated by hydrostatic pressure in a deep sea bacterium. *Nature*, v.342, 1989. pp.572-574.

Haygood, M. G. Relationship of the luminous bacterial symbiont of the Caribbean flashlight fish, *Kryptophanaron alfredi* (family Anomalopidae) to other luminous bacteria based on bacterial luciferase (luxA) genes. *Archives of Microbiology*, v.154, 1990. pp.496-503.

Vacquier, V. D., K. R. Carner, and C. D. Stout. Species specific sequences of the abalone lysin: the sperm protein that dissolves a hole in the egg envelope. *Proceedings of the National Academy of Sciences U.S.A.*, v.87, 1990. pp.5792-5797.

Marine Physical Laboratory

MPL

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.

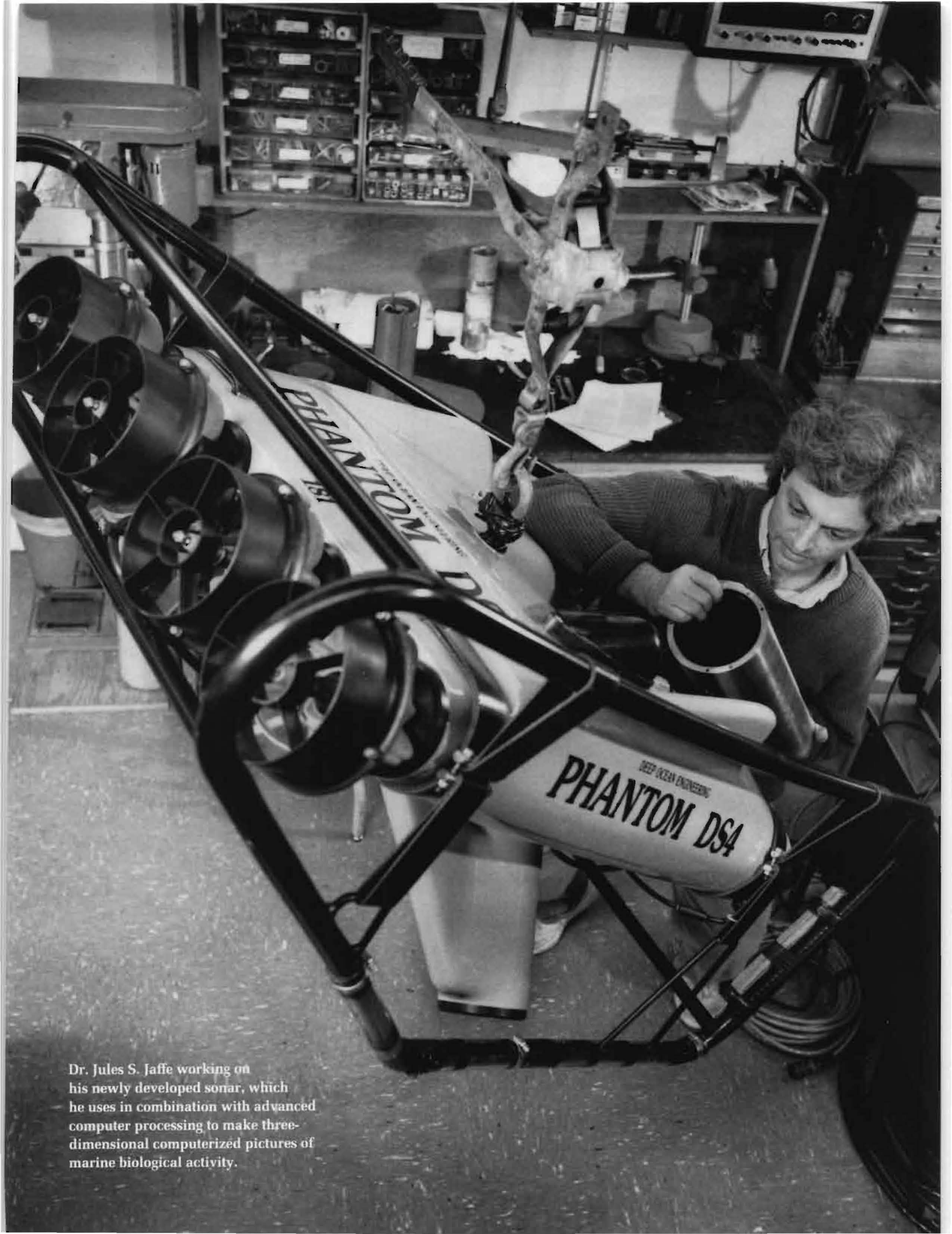
Scientific papers listed in the Publications section will lead the reader to a more in-depth coverage of the topics discussed in the Research Activities section.

SCIENTISTS AT THE MARINE PHYSICAL LABORATORY (MPL) focus on research programs in ocean acoustics, physical oceanography, and marine geophysics. Their research includes observations of the sea floor and within the water column and requires the development of instrumentation, platforms, and signal processing techniques. MPL scientists work on board vessels, R/P FLIP, research submarines, and they also deploy unmanned remotely operated instrument systems.

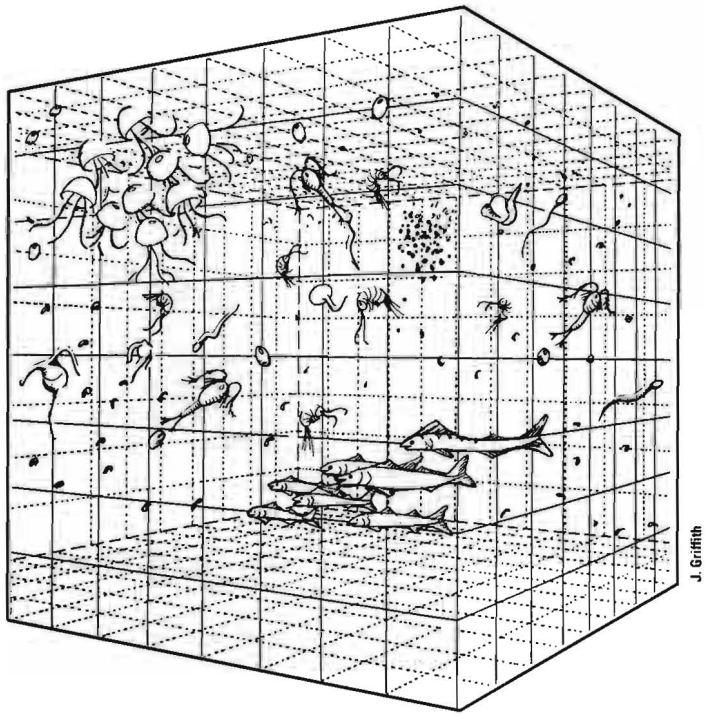
Deep Tow Research

The Deep Tow research group, directed by Dr. Fred N. Spiess, concentrated on completing a system for working from R/V *Melville*–enabling scientists to install and monitor equipment in Ocean Drilling Program holes. Their work included developing a logging tool to measure hole diameter, tilt and temperature as a function of pressure. They constructed telemetry and interface equipment to monitor four, three-component seismograph units. Group scientists also implemented a dynamic positioning system for R/V *Melville* for long-term monitoring of the downhole equipment. This system held *Melville* within 20 m of the reference point for days at a time, using a long baseline acoustic transponder system. The Low Frequency Acoustic Seismic Experiment (LFASE) started with borehole reconnaissance at two holes near 25°N, 68°W in 4,500-m water. Both were found to be filled with sediment that had welled from below the 50-m cased section. The first wireline re-entry of a deep water drill hole from a surface ship other than a drilling ship was accomplished at hole 534 (28°20'N, 25°23'W) when researchers found it open and logged down to 150 m below the sea floor at 5,000 m. Next, group scientists placed twelve ocean bottom seismographs near the hole and installed the seismograph string. They monitored the geophones for two days, then they decoupled and left the area. A thruster vehicle system was used to retrieve the equipment.

The group's marine geodesy efforts were focused on improving precision transponder reliability and working range. On a short operation they used a



Dr. Jules S. Jaffe working on his newly developed sonar, which he uses in combination with advanced computer processing to make three-dimensional computerized pictures of marine biological activity.



An artist's rendering of a three-dimensional diagram of marine biological activity that will be generated by the sonar. This will allow Dr. Jaffe to assess populations, groupings, and behavioral changes of organisms during a 24-hour day.

combined georeceiver positioning system (GPS) and acoustics on a float to locate a sea-floor transponder relative to GPS coordinates. Data reduction continues with an optimistic outlook for the future implementation of a total system.

Waves and Currents

Dr. Jerome A. Smith is studying the interactions of surface waves and currents in the open ocean. The combined effects of wind-drift and waves can cause the formation of Langmuir circulation in the top layer of the ocean. Langmuir circulation, which has potential importance as a mechanism for mixing wind-generated momentum throughout the mixed layer, has proven difficult to observe in the open ocean. Recent observations with 75 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 system as previously configured (2 x 20 m). The same systems demonstrated a capability for measuring the surface wavefield.

With such surface wave and current measurements in mind, a 75 kHz system was designed to achieve 10 m resolution, and a new 200 kHz system was developed with a range resolution of about 3 m (corresponding to waves with a 2 sec period at the cut-off). These systems were deployed from FLIP as part of the Surface Wave Processes Project (SWAPP). As a surface-wave, directional array, these sonar systems can distinguish between oppositely directed wave components in the open ocean. Such components are thought to give rise to pressure fluctuations at the sea floor microseisms, as measured by others.

In addition to resolving the wave orbital velocities and the mixed layer currents, the sonar backscatter intensities provide information about bubble density in the near-surface layer. By mapping both velocity and intensity down to 3 m (roughly the size of bubble patches), it should be possible to investigate the "life cycle" of the bubbles, from formation under breaking waves to subduction and dissolution as the mixed layer currents advect them.

On returning from the SWAPP experiment, Dr. Smith's group began analysis of the surface wave and Langmuir cell data. They are searching for the signature of low frequency internal waves in the sea surface Doppler sonar records. Drs. Robert Pinkel and Jeffrey T. Sherman are examining deep internal wave information obtained from down-looking sonars that were also mounted on FLIP.

Seismic Noise

Dr. LeRoy M. Dorman also participated in the SWAPP experiment in the Northeast Pacific. The characteristics of wind waves and swell were measured with extensive instrumentation. These waves are a prominent source of seismic noise. Dr. Dorman used ocean bottom seismographs to measure the

sea-floor seismic noise and fired small explosions on the sea floor as part of a seismic refraction and interface wave study of sea-floor structure. The shear velocity is very low in the surficial sediments and the resulting waveguide has a profound influence on the propagation of sea-floor noise.

Drs. Dorman and Hildebrand helped design and construct more than 30 ocean bottom seismographs. These instruments have improved clock stability, recording capacity, and endurance compared to the instruments Dr. Dorman operated earlier. The improved performance allows new classes of array and tomographic experiments.

Underwater Acoustics

Dr. William S. Hodgkiss's group focuses on underwater acoustics and signal processing, emphasizing the Swallow float array program. An array was fabricated and taken to sea to measure infrasonic acoustic ambient ocean noise in the 1-20 Hz frequency region. The Swallow floats are freely drifting and each buoy pings on schedule thus providing a localization signal that is received by the other buoys. When locations of all the elements are known, coherent processing of the array element outputs (beamforming) can be accomplished.

Drs. Hildebrand and Hodgkiss deployed a long vertical line array off R/P FLIP as part of a major acoustics experiment. Constrained to a watch circle of ~100-m diameter because of a deep-sea, 3-point moor, R/P FLIP provided a stable platform from which to deploy and monitor the hydrophone array. The vertical array consisted of 25 modular sections with 8 element/sections or 200 hydrophones over a 3 km aperture. The array did not remain perfectly straight during the experiment, and the positions of the sections in 3-dimensional space were located via 12 kHz acoustic transponders placed on the sea floor around the array.

Two concurrent experiments were conducted taking advantage of the large aperture array and the extensive environmental data being collected. In the Downslope Conversion Experiment the scientists studied 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 recently surveyed by Sea Beam sonar specifically for this experiment.

The second experiment, part of the Acoustic Transients Accelerated Research Initiative, consisted of a deep water component and a shallow water component. In both cases, a selection of transient signals (short-duration waveforms with broad spectral content) were transmitted for reception by the R/P FLIP array in the first case, and a bottom-moored vertical array in the vicinity of the downslope source tows in the second case.

Optical Systems

Richard W. Johnson's Optical Systems Group continues to use and enhance the Whole Sky and Horizon imaging systems built at MPL. The two video based, computer controlled systems are ready for use in most daytime data acquisition tasks. The group is extending each system's operational window, applying the rapidly growing data base to model validation studies, and developing real-time case study capabilities. Jack R. Varah is extending the camera's low flux level capabilities to enable nighttime operations. The basic charge injection device camera was modified to operate in either injection inhibit mode for on-chip integration, or in full intensified mode using an ITT single channel plate intensifier. Mock-ups of both modes are being run at various MPL test sites under a variety of moonlight and starlight illumination levels.

The group's six-station nationwide network of daytime Whole Sky Imagers (WSI) provides about seven gigabytes of imagery per week for the project archive. This image oriented data base is being used by Dr. Thomas L. Koehler to develop techniques for the automatic extraction of cloud-free line of sight (CFLOS) and cloud-free arc (CFARC) statistics. Several special applications of the Whole Sky Imager require real-time processing for local cloud cover, and CFLOS/CFARC locations within the sky dome. Janet E. Shields modified a software and algorithm package to provide this quick response and the operational system has been successfully deployed.

The Horizon Scanning Imager (HSI) is an automatic visibility meter based upon the measurement of the apparent contrast of random targets within its field of view. Two systems are currently in operation and their daytime data bases are undergoing continuous evaluation and analysis. Their conversion to nighttime operation based upon the detection of distant lights is under way. Dr. Eugene M. Zawadzki is working to exploit the WSI and HSI data bases in ways that require innovative implementation of software and algorithm upgrades.

Electromagnetics

Dr. Spahr C. Webb is developing a transient electromagnetic sounding system. When towed along the sea floor, this device measures the electrical conductivity of the near-surface rocks. The system is designed to study sulphide mineralization and hydrothermal processes at sedimented ridge crests. A few measurements were obtained from bare rock at the top of Fieberling Guyot.

Six instruments were deployed at a site on the continental rise off central Oregon to study low frequency sound and offshore infragravity waves. Two new systems were initiated; an optical disk was used to record data, and an external seismometer package was deployed from one instrument.

Newtonian Gravitational Constant

Drs. John A. Hildebrand and Mark A. Zumberge continue their studies of the Newtonian gravitational constant *G*, a fundamental parameter of physics relating the gravitational force between body masses by an inverse square of the separation. Gravity acceleration measurements, the medium density, and the ocean location can be used to back-calculate for *G*. The advantages of an oceanic measurement of *G* over one made on land or ice include the high accuracy with which water density can be measured in three dimensions in the ocean, and the ability to make gravity measurements over two-dimensional planes on the sea floor, in the water column, and on sea surface. Data collection components of the project were completed on a joint expedition with R/V *New Horizon* and research submarine USS *Dolphin*, to the *G* site at approximately 35°N, 132°W. An acoustic transponder network was established over a 20 km x 20 km area; the network supplied independent navigation for *New Horizon* and *Dolphin*. Scientists aboard *New Horizon* conducted a sea-floor gravity survey with 29 stations and a number of CTD and XBT casts to define the water density profile. The sea-floor gravity survey covered a 15 km x 15 km area with about 1.5 km between stations. A mid-water gravity survey was conducted from *Dolphin* at depths to 917 m using a shipboard gravimeter installed within the submarine. The *Dolphin* gravimeter collected continuous profiles on six dives. Both the *New Horizon* and *Dolphin* gravimeters were tied to absolute gravity measurement sites immediately before and immediately after the seagoing expeditions.

Special Studies

Dr. Andrew G. Dickson's group is developing the background to prepare and certify reference materials for the quality control of oceanic measurements of carbon dioxide. They are improving the method for analysis of carbon dioxide in seawater. Preliminary results indicate that this method is precise (±0.02%) and is accurate to better than 1μ mol kg^{-1}.

Dr. Jules S. Jaffe is developing and testing an electronics system that uses sound to make three-dimensional computerized pictures of biological activity, ranging from plankton to large fish. The image field would be extensive enough to assess both the marine populations and their groupings and environmental behavioral changes in relation to night and day. The system combines newly developed sonar (sound navigation and ranging) techniques and advanced computer processing.

Dr. Christian de Moustier analyzes acoustic reverberation backscatter from the sea floor or deep scattering layers in the ocean. Data sets under investigation include complex acoustic data recorded from a 12 kHz Sea Beam multibeam echo sounder and from the SeaMARC II bathymetric side scan sonar system (11-12 kHz). Dr. de Moustier and a colleague have devised a method to convert acoustic measurements made with the Sea Beam system into a set of parameters used for remote sea-floor classification. Using such parameters, they are now exploring the applicability of existing neural network algorithms to the sea-floor classification problem.

Dr. Mohammad Masnadi-Shirazi is working with Dr. de Moustier on new processing techniques to convert differential acoustic phase measurements made with the SeaMARC II system into bathymetry. In conjunction, Drs. Pierre Cervenka and de Moustier are working on processing methods to relocate the pixels of a SeaMARC II sidescan sonar image, based on a gridded bathymetric map, which was compiled with Sea Beam soundings collected with the image during leg 18 of Scripps's Roundabout Expedition. Improvements in both the bathymetric processing and the pixel positioning are important steps for acoustic backscatter studies and, by extension, for geologic interpretation of the terrain surveyed.

Marine Research Division

MRD

Mary Kay Harper identifying a marine invertebrate to be used in an antitumor study.

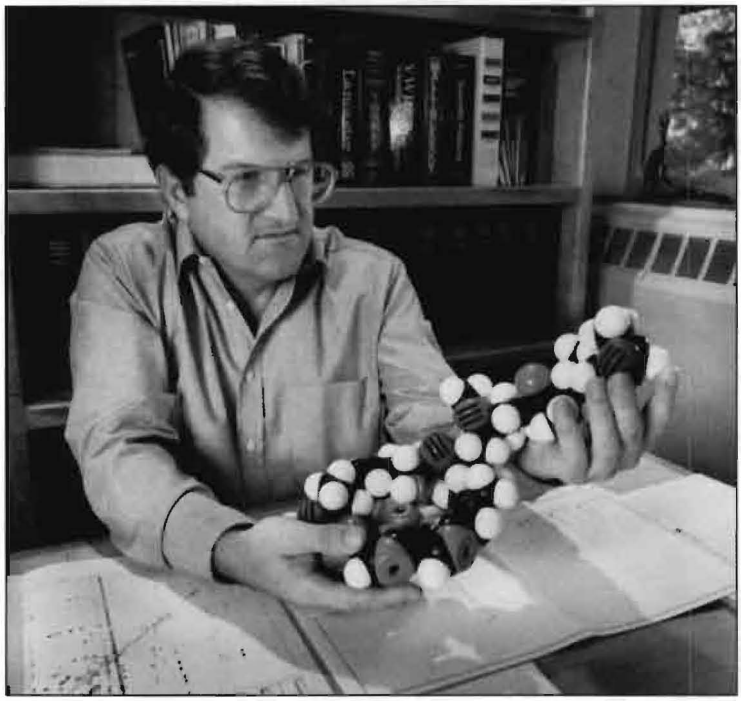
THE NEWLY FORMED MARINE RESEARCH DIVISION, directed by Dr. William H. Fenical, encompasses investigations in marine biology, marine chemistry, physical oceanography, and ocean engineering. Some of these programs are described here.

Dr. Richard J. Seymour's Ocean Engineering Group improved the fatigue life of moorings at sea by using high performance composites and new manufacturing methodologies. They are adapting the work system of the Remote Underwater Manipulator III to study the biological impacts of mining manganese nodules. This includes the equipment to simulate mining impacts and the sampling devices used by the program biologists.

Ocean Engineering Group scientists Dr. Jules S. Jaffe and graduate student Edith L. Gallagher are developing an acoustical device for measuring the magnitude of bedload transport of sand by waves and currents. Graduate student Guoxiong Liang is studying the sand movement near the jettied mouth of the Colorado River in Texas. He is assessing complex orthogonal functions as a tool for tracking wave-like features in the sediment movement.

Graduate student David B. King finished an extensive series of laboratory experiments on bedload transport of sand under oscillatory flows, established the importance of accelerative forces to this transport, and obtained the first data on the effects of a sloping bed. Others in the Ocean Engineering Group are working on instrumentation that includes a low cost acoustical system for measuring long waves from piers and a processor-controlled remote station for gathering field data. Graduate student Forrest E. Sloan is studying changes in mechanical properties of graphite-reinforced composite structures in seawater. He has shown that their tensile properties are unaffected by sea-

Dr. D. John Faulkner examines a molecular model of halichondramide.



water except under certain conditions of electrochemical exposure, in which they are rapidly damaged. Graduate student Michele S. Okihiro is studying the transfer of energy from wind waves to forced long waves and the subsequent excitation of resonances (seiching) in a Hawaiian harbor. She developed a successful model to predict harbor seiching from the incident wind-wave spectrum.

Dr. Toyoaki Nogami and colleagues are revising the analysis method of seismic response in offshore pile-supported structures. Dr. Nogami is developing a model to analyze the foundations installed in sea-floor sediments. This model will be calibrated using records from a fully instrumented, offshore platform, that will record earthquake responses through 1992. A method to compute the response of waterfront structures to strong earthquakes is being developed so that precautions can be taken against liquefaction. Dr. Nogami bases his method on a finite element scheme formulated for the water-structure-soil system and takes into account the pore fluid pressure in and nonlinear behavior of the soil mass. Dr. Nogami is also studying massive sea-floor failures that result from storm waves. His goal is to create a way to evaluate permanent sea-floor downslope movement. This will be done with analytical methods, model experiments, and case histories.

Identification of isolated new antitumor agents from marine invertebrates is the focus of a new research program led by Dr. D. John Faulkner's group. The project is supported through the National Cooperative Drug Development Program and involves scientists from several universities and a pharmaceutical company. The collaboration of university and industrial research groups will enable active compounds discovered by university groups to receive full evaluation, testing, and clinical trials sponsored by industry. Initial cooperative results showed that a known group of compounds was very effective in a new DNA repair assay. The same assay was used to discover a very active compound from a tunicate; the compound has now been identified, and experiments to determine a possible mechanism of action are under way.

Another new study is the role of symbionts in the production of marine natural products. While these investigations are of fundamental scientific interest, they may also make it possible to obtain reliable supplies of complex molecules by growing the symbionts under culture conditions rather than collecting the host organisms.

Dr. Jeffrey L. Bada's group focused on several analytical organic geochemistry projects. Graduate student Meixun Zhao continued work on extraterrestrial amino acids in the Cretaceous/Tertiary boundary layer after finding the compounds a-amino isobutyric acid and racemic isovaline in sediments from Denmark. His results strongly support the hypothesis that the mass extinctions in the paleontological record of that period were caused by an extraterrestrial impact. Graduate student Robert F. Chen is studying the fluorescent compounds in seawater and sedimentary pore waters. He found differences between Atlantic and Pacific fluorescence and between surface waters and deep waters, which suggest that fluorescence is a valuable tracer of water masses. Graduate student Michael R. Wing constructed and used a two-step laser mass spectrometer to analyze the aromatic hydrocarbons in marine and geochemical materials. Graduate student John E. Mak investigated the ^{14}C of atmospheric carbon monoxide in the Southern Hemisphere. In a collaborative effort, Dr. Bada studied bomb-related ^{14}C and stable isotopes in moose teeth on Isle Royal, Michigan, to assess carbon turnover in biological tissues. The carbon isotope record reflects changes in the forest ecosystem and anthropogenic alterations to the global atmospheric carbon cycle.

Dr. Joris M. Gieskes took part in leg 131 of the Ocean Drilling Program cruise at Nankai Trough.

Interstitial waters were retrieved at closely spaced intervals from Site 808, which reached the oceanic basement. Scientists drilled through the décollement zone that separates underplating sediments from off-scraped sediments in the accretionary complex. Collaborative data indicated that low chloride fluids observed in subduction zones and other continental margin settings may result from dilution. Clay dehydration reactions and perhaps potential ion filtration by fluid movement through semi-permeable clay membranes were seen as causes for this dilution.

Dr. Peter M. Williams continued his studies of organic carbon cycling. He and colleagues studied carbon cycling in north central Pacific and Sargasso Sea oligotrophic gyres and in the Santa Monica Basin off Southern California. Measurements of isotopic signatures (^{14}C, ^{13}C, ^{15}N) in the soluble and particulate organic phases show that the ^{14}C content of suspended and sinking particulate organic matter decreases with depth at all three sites. This indicates a deep source of "older" carbon not derived directly from photosynthetically reduced carbon in the surface waters. Their measurements also indicate that UV-oxidizable, dissolved organic matter in deep water has ^{14}C about 4,000 years old in the Atlantic, 6,000 years in the Pacific, and 5,000 years in the Santa Monica Basin. This fraction of the dissolved organic matter is, on average, cycled four to six times between surface and deep waters. They found that the organic phases in the basin contain less than 10 percent terrestrially derived organic matter. Dr. James E. Bauer is determining the ^{14}C content of the "extra" dissolved organic matter from high temperature combustion. Total dissolved organic carbon and nitrogen concentrations at all sites are being measured by high temperature combustion techniques.

Scientists in the Polar Research Program, directed by Dr. Osmund Holm-Hansen, worked on several projects in the Antarctic. At Palmer Station they studied the effects of solar ultraviolet radiation (UVR) on phytoplankton, and the consequences on the marine food web of ozone depletion in the stratosphere over Antarctica during the austral spring season. These studies were concentrated in October, the period of maximal development of the ozone hole. Results indicated that primary production rates in the upper 5 m of the water column were depressed about 25% by UVR, but the total depression of phytoplankton photosynthesis in the upper 50 m amounted to less than 5%. Approximately 60% of this inhibition was caused by UV-B (280-320 nm) and 40% by UV-A (320-400 nm) radiation. In conjunction with these studies, Dr. B. Gregory Mitchell measured the spectral attenuation of UVR and visible light in the water column. He also analyzed various aspects of phytoplankton physiology as related to UVR. Dr. Maria Vernet studied photoadaptation in response to enhanced UVR; and she found that Antarctic phytoplankton can synthesize protective UV-absorbing compounds.

Polar Research Program scientists focused on food web dynamics in Antarctic waters as influenced by physical, chemical, and optical factors. The RACER (Research on Antarctic Coastal Ecosystem Rates) program researchers took samples in a ~4,000-km^2 grid in Gerlache Strait to elucidate the development of the spring phytoplankton bloom. They found that high phytoplankton biomass and high rates of primary production (2-5 gms carbon m^2 day-1) in coastal waters correlated with shallow (<20 m), stable upper mixed layers with lowered salinity values and elevated temperatures. U.S. Antarctic Marine Living Resources program studies were centered in a 26,000 square km area near Elephant Island. Program researchers dealt with phytoplankton-krill interactions and how area populations are affected by the various water masses and frontal systems.

Dr. Vernet focuses on the distribution, abundance, function, and fate of pigments synthesized by marine phytoplankton. Her concerns include photoadaptive pigment processes, specific growth rate calculations by radiocarbon labeling of chlorophyll-*a*, estimation of floristic composition of natural assemblages by pigment analysis, and pigment budget modeling.

Dr. Mitchell studied the optical properties of ocean water, their relationship to the physiological state, and activity of phytoplankton and their application to remote sensing. These laboratory studies were made in quasi-natural conditions using the Scripps deep tank. He also took part in the Coordinated Eastern Arctic Experiment program, which is focused on the Greenland Sea ice edge zone.

The Marine Bio-Optics Group led by Dr. Raymond C. Smith and Karen S. Baker continued remote sensing investigations assessing links between optics and wavelength-dependent productivity of marine phytoplankton. An underwater ultraviolet instrument has been developed and atmospheric algorithms created for bio-optical field work in the Antarctic.

Neurobiology Unit

NU

Graduate student Georg F. Striedter touches up a sketch of the brain of a South American electroreceptive gymnotoid fish.

THE NEUROBIOLOGY UNIT, a joint program of Scripps and the UCSD School of Medicine, is part of the Marine Biomedical Program. Unit scientists, including five faculty members, ten postdoctoral associates, and several graduate students focus on the structure and function of the nervous system in animals–particularly bony and cartilaginous fishes.

Dr. Helmut Wicht has been studying the brains of two groups of fishes–hagfishes and lampreys–which are believed to be early offshoots of the line leading to the main vertebrate radiation (sharks, bony fishes, terrestrial vertebrates). The lamprey brain is relatively small and displays a low degree of overall complexity. The hagfish brain, however, is relatively large, well differentiated, and contains a multitude of subdivisions that are still poorly understood. Dr. Wicht is attempting to relate this complex pattern to the simpler ones found in lampreys and some other vertebrates. The ultimate goal of such studies is to reconstruct the anatomical conditions of the brain at the starting point of vertebrate phylogeny.

As part of his research on bony fishes, graduate student Georg F. Striedter found that sensory information from the receptors of the auditory, electrosensory, and mechanosensory lateral line systems probably converge within a single cell group at the level of the diencephalon (between midbrain and forebrain) in the great order of catfishes. He showed how the neural connections of that cell group have changed with the evolution of specialized auditory and electrosensory systems in these and other ostariophysine teleosts.

Physical Oceanography Research Division

PORD

Dr. Myrl C. Hendershott and colleagues from the Centro de Investigación Científica y de Educación Superior, Ensenada, Mexico, Drs. Antoine Badan-Dangon and Miguel F. Lavin, discuss their Gulf of California study.

INVESTIGATORS IN THE NEWLY FORMED Physical Oceanography Research Division (PORD) study problems in physical oceanography and related areas of marine meteorology. Here, three ongoing PORD studies are discussed as examples of division research.

Air-Sea Interaction Studies

Dr. David P. Rogers is using both in situ measurements and numerical models of the turbulent structure of the marine atmosphere to understand how it and the upper ocean are modified by interactions between the air and sea. He is studying how variability in the marine atmosphere affects mixing in the upper ocean and distribution of sea surface temperature and wind-driven waves. This involves understanding the processes that vary the wind, atmospheric temperature, water vapor, and aerosol fields in the first kilometer above the ocean.

Past work has revealed that the spatial variability of sea-surface temperature on a scale of 200 km or less gives rise to horizontal variability on a similar scale in the atmosphere. Measurements obtained during the Frontal Air-Sea Interaction Experiment (FASINEX) have shown that variations in the sea-surface temperature over a few kilometers can substantially change the dynamic and thermodynamic structure of the marine atmosphere which, in turn, may modify the surface temperature field.

FASINEX data analysis has focused on air flowing from warm to cool water across a sharp surface temperature front or discontinuity. Upstream of the front, the air is in equilibrium with the surface conditions. As the air passes over the surface temperature discontinuity, this balance is disturbed and the atmosphere responds to the new surface conditions, thus creating a stable internal

boundary layer from the surface to a height of ~100 m. This layer is characterized by low wind speeds, reduced fluxes, lower temperatures, and higher mixing ratios as compared to the atmospheric structure on the warm side of the front. Of particular importance is the large and persistent decrease in the surface stress from the warm to the cool water, which indicates that the atmospheric forcing of the ocean is much weaker on the cooler side of the ocean front. Thus scientists can conclude that heterogeneous surface conditions give rise to substantial variability in the marine atmosphere that can feed back to the variability in the ocean.

The small-scale variability observed during FASINEX appears to be ubiquitous in the open ocean, but is particularly important over the continental shelf where various effects including topographically forced winds, directional waves, and upwelling enhance the variability of the ocean-atmosphere exchange processes. Recent marine atmospheric measurements highlight the complex interactions between processes in a coastal environment. A combination of sea-surface temperature gradients, strong winds, and warm air produced a shallow stable layer that limited the vertical transport of aerosols and moisture. This reduced the turbulent transfer of energy and momentum across the ocean-atmosphere interface.

Long-range aircraft are used in assessing the variability of the surface processes and the structure of the atmosphere over the ocean. The aircraft are equipped to make very high resolution measurements of the turbulent structure of the atmosphere from a minimum height of about 30 m. Covariances of the vertical velocity and the horizontal velocity, temperature, and water vapor mixing ratio, measured at the lowest level, can be extrapolated to the surface to estimate the fluxes. These estimates are used to determine the extent of the atmospheric forcing of the upper ocean. During FASINEX, two aircraft were used to make simultaneous measurements of the turbulence fields at 30 m and 100 m. These flights provided some of the first information on the real-time vertical structure of the momentum flux over a highly heterogeneous surface temperature field.

Circulation in the Gulf of California

The circulation of the Gulf of California has long been of scientific interest; the first hydrographic expedition there was in 1885. The gulf stretches over 1,100 km between Baja California and Sonora in mainland Mexico. The southern and central gulf are about 100 km wide, and several thousand meters deep. The central gulf is separated from the broader and shallower northern gulf by a chain of islands with three major sills. They are the narrow Salsipuedes Sill south of Ballenas Canal (the sill nearest Baja California), the broad sill between the southward subsurface extension of San Lorenzo Island and San Esteban Island, and the little-explored sill between San Esteban Island and Tiburon Island. (The narrow channel between Tiburon Island and mainland Mexico is too shallow to carry significant amounts of water.)

In joint programs with Mexican researchers, Scripps scientists continue to work in the Gulf of California. In January 1990, Dr. Antoine Badan-Dangon of Mexico and Dr. Myrl C. Hendershott mounted an acoustic Doppler current profiler on the Mexican research vessel *El Puma*. They obtained a large number of vertical profiles of the flow from top to bottom along the ship's track as they surveyed the region around the islands and a part of the northern gulf.

Some of the scientists' striking results have to do with the exchange of water between the gulf and the Pacific. The gulf as a whole accepts cold and relatively fresh Pacific water and returns warmer and more saline water. This circulation is important because it brings nutrients into the shallow and tidally well-mixed northern gulf, making it a region of great biological productivity. In 1939 scientists had postulated that such a circulation must exist, but their observations were not adequate to reveal it. The apparent similarity between the northern gulf and the Mediterranean–over both evaporation exceeds precipitation and both are connected to adjacent deep water via (a) narrow passage(s) with shallow sill(s)–would suggest that the gulf should import cold and relatively fresh Pacific water near the surface and return warm but salty water to the Pacific at depth. Yet, current meters deployed near the bottom of Salsipuedes Sill in 1985 suggested circulation in the opposite sense. Analysis of hydrographic and meteorological data showed that in spite of strong evaporation, the northern gulf actually gains heat from the atmosphere, so that the salty water it exports may be warm enough to flow out near the surface and not at depth.

Dr. Nan A. Bray synthesized historical hydrographic and meteorological data as well as data she took on several cruises with Mexican investigators and demonstrated that relatively fresh Pacific water flows into the northern gulf at depth over the sills, while warm but salty water leaves the north-

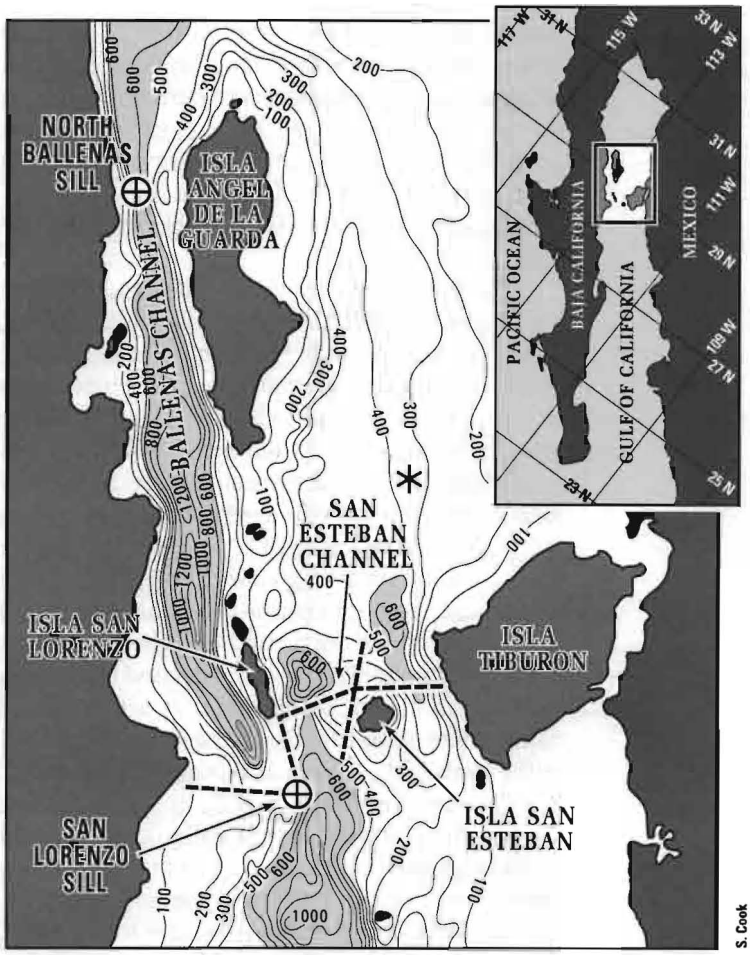
ern gulf nearer (although not yet at) the surface. The annual average rate of exchange was about 0.9 Sverdrups (one Sverdrup is one million cubic meters of water per second). The detailed manner in which that exchange is driven, how it is partitioned between vertical and lateral flow, and how it is partitioned between the different sills remains unclear.

Drs. Badan-Dangon and Hendershott traversed the sills repeatedly with the profiler at neap tides, when tidal currents are relatively small, looking directly at the exchange circulation to find the effect of each sill. They moored current meters near the bottom at both the south and north sills of Ballenas Canal to see whether the deep inflow over the south Salsipuedes Sill of Ballenas, which they had seen on an earlier mooring, is part of the overall northern-central gulf meridional exchange.

Although near-bottom currents over both the south and north sills of Ballenas Canal alternate between up and down gulf directions at spring tides, the current meter records at the south Salsipuedes Sill show that, at that sill, near-bottom currents are almost entirely toward the northern gulf at neap tides. Ballenas Canal is narrow but more than 1,000 m deep. The deep water is much warmer and hence lighter than that found just south of the south Salsipuedes Sill, probably on account of vertical tidal mixing. This encourages the flow of deep water northward over Salsipuedes Sill in much the same manner that the greater salinity and hence density of deep Mediterranean water encourages its flow out of the Mediterranean over the sills at Gibraltar. There is thus a net flow of deep water into Ballenas Canal from the central gulf. Higher up in the water column, the mooring showed flow southward out of Ballenas Canal towards the central gulf. The amount of water exchanged between Ballenas Canal and the central gulf in this section alone is roughly 0.2 Sverdrups, an appreciable part of the 0.9 Sverdrups earlier estimated from hydrography.

Ballenas Canal thus appears to play an important role in the exchange of water between the central and the northern Gulf of California. How much of the deep water entering Ballenas Canal over Salsipuedes Sill gets into the far northern gulf over the north sill is not yet known. The current meter records at the north sill of Ballenas Canal indicate some net flow to the north at the deepest instrument (the flow is mainly to the north on those days when the tidal currents are small). However, this net flow is not as strong as that at the south sill. It remains to be seen whether a clearer picture will emerge from a combination of the current meter records and the various profiler sections taken along the north sill. Profiler transects across the other sills also show deep northward flow, both at neap tides and at spring tides. However, these transects had larger contributions from tidal currents, and they will have to be carefully removed before it will be possible to partition the deep flow accurately by sill.

Map of Gulf of California area under study by Dr. Hendershott and colleagues.



Atmospheric Forcing of the Deep Ocean

The patient observer at the ocean's shore notices that atmospheric winds force waves and currents at the water's surface. What is less obvious is that the effect of the winds (and also the effect of air pressure fluctuations) can penetrate deep into the ocean. These effects easily reach even bottom depths that are far from coasts and exceed several kilometers. A large 1986 experiment fielded by PORD scientists has yielded evidence of direct atmospheric

forcing of deep ocean currents, which fluctuate from a few days to several months. Such motions, although quite weak relative to currents very near the ocean's surface, may have a profound effect upon how water properties are mixed and how atmospheric energy is dissipated in the ocean, because they dominate a large fraction of the water column.

The Barotropic, ElectroMagnetic and Pressure Experiment (BEMPEX) consisted of a 44-instrument array positioned on the North Pacific sea floor for almost one year. The array measured fluctuations in pressure (which are closely linked to water movement according to the hydrodynamic equations) and electric and magnetic fields. At periods longer than a few days the electric field fluctuations are directly related to water movement, in this case the top-to-bottom average currents passing by the instrument. At shorter periods both the electric and magnetic fields are dominated by signals generated in the ionosphere. The latter can be used to infer the variation of electrical properties as a function of depth in the earth beneath the ocean, as discussed in the Highlights section of this annual report.

The instruments deployed in BEMPEX, designed and built by Dr. Jean H. Filloux, incorporate a variety of novel sensors to obtain high sensitivity and accuracy in sea-floor environments–with temperatures near freezing and pressures hundreds of times greater than sea level air pressure. The heart of the pressure gauge is a coiled metal tube called a Bourdon tube, the inside of which is connected to the external environment. As the water pressure changes around the instrument, the Bourdon tube twists, uncoiling or coiling in response to greater or lesser pressures. The twisting of the tube is detected by bouncing light off a mirror attached to the end of the tube. Dr. Filloux's magnetometers also employ optical readouts, but in this case the mirrors are attached to magnets aligned along three orthogonal axes, two horizontal and one vertical. As the ambient magnetic field along any direction changes, the magnet in that direction moves, changing the position of the mirror, which is registered optically. The electric field sensors are essentially voltmeters, where the voltage is measured over a span of at least six meters using silver chloride salt bridge electrodes. An ingenious, low-power magnetic switch periodically reverses the polarity of the electrodes to completely eliminate biases that can result from corrosion and component fatigue.

The BEMPEX pressure and electric field data sets have shown that fluctuations in the deep North Pacific Ocean at periods longer than a few days are strongly related to atmospheric forcing, while the specific kinds of ocean responses at different periods have provided some surprises. The deep ocean's response is primarily dependent upon local winds at periods around a few days; that is, the ocean's response does not propagate away from the forcing region. Therefore, every patch of ocean has motions at these periods that are dictated essentially by the winds directly above. At longer periods, the ocean supports an unusual kind of wave motion, quite dissimilar from the surface gravity waves most familiar to the shorebound observer, that allows motions in the deep ocean to propagate far from the forcing region. The scientists found the direction of propagation to be quite variable in BEMPEX, contrary to existing models. While such propagating waves complicate the determination of cause and effect, Drs. Alan D. Chave, Filloux, and Douglas S. Luther have distinguished local from non-local forcing with the BEMPEX data set, partly because of the improved quality of estimates of surface winds provided by the U.S. Navy.

Dr. Filloux's remarkable instruments also yielded new descriptions of deep oceanic motions at periods as short as 2 minutes–the domain of gravity waves such as tsunamis. BEMPEX revealed the gravity waves at periods shorter than 15 minutes exhibit regular propagation characteristics just like the 5-10 second swell that delights beachgoers. However at periods of 15-120 minutes, the gravity wave motion appears to be organized in what are called standing oscillations, not unlike the sloshing motion in bathtubs. However in the bathtub there is a single nodal line, across the middle of the tub, where the water elevation changes little compared to the ends of the tub, whereas in the ocean the 15-120-minute oscillations have many dozens of nodal lines. The existence of such standing oscillations is important to understanding how wave energy is dissipated in the ocean.

Physiological Research Laboratory

PRL

Graduate student Wendy L. Ryan observes the formation of bubbles during rapid decompression.

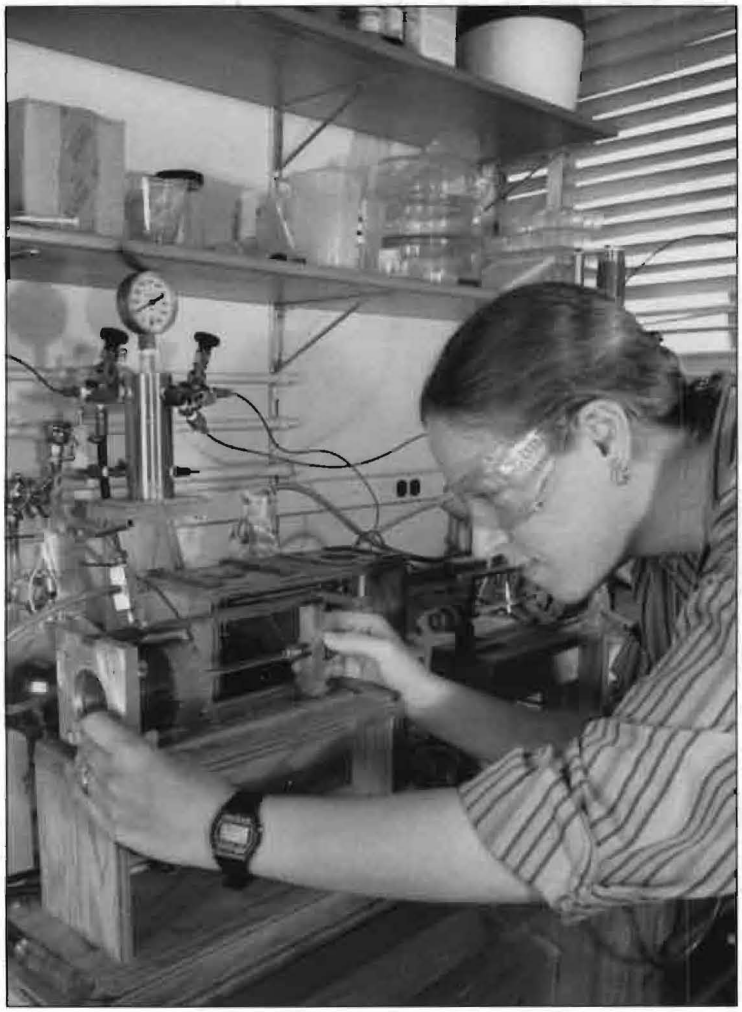
SCIENTISTS IN THE PHYSIOLOGICAL RESEARCH LABORATORY (PRL) study the behavioral, physiological, and biochemical adaptations of aquatic and terrestrial animals. In this report recent findings of three PRL scientists and their students are highlighted.

Scientists in Dr. Gerald L. Kooyman's laboratory studied the ecology of emperor penguins at Cape Washington, Antarctica. Included in this field research were Dr. Scott A. Eckert and others who completed a successful 75-day stay at a remote camp on sea ice. Laboratory scientists working at the Scripps Hydraulic Laboratory's flume measured the emperor penguins' swimming metabolic rates and heart rates up to maximum oxygen consumption. The three birds used in this study were brought back from Antarctica in 1988. The trained birds swam well and the research group, including Drs. Paul J. Ponganis, Eckert, and others, obtained excellent data. From these two studies it has become clear that emperor penguins are high performance divers in every sense, from depth and breath-hold capacity to swimming speed and high aerobic capacity.

Dr. Jeffrey B. Graham investigated the control of cardiac activity in air-breathing fishes. Work with the tropical swamp eel (*Monopterus*) demonstrated the actions of mechanoreceptors and chemoreceptors in eliciting and regulating tachycardia (increased heart rate) following an air gulp. Dr. Graham collaborated with Dr. N. Chin Lai, and Drs. Valmik Bhargava and Ralph Shabetai, UCSD School of Medicine, in angiographic studies of shark gill perfusion. This research led to a model for branchial O_2 transfer that examines blood dissociation curve characteristics in the domain of time.

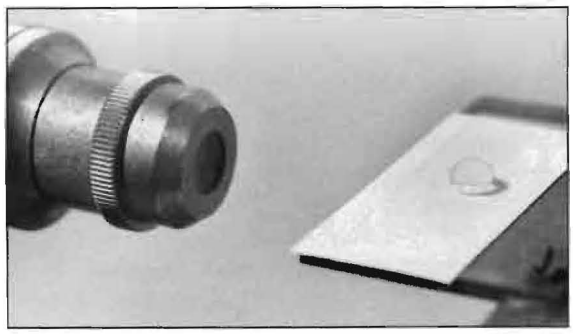
Graduate student Heidi Dewar used Dr. Graham's water treadmill in her investigation of

Wendy Ryan sets up a pressure chamber to measure bubble formation in a liquid.

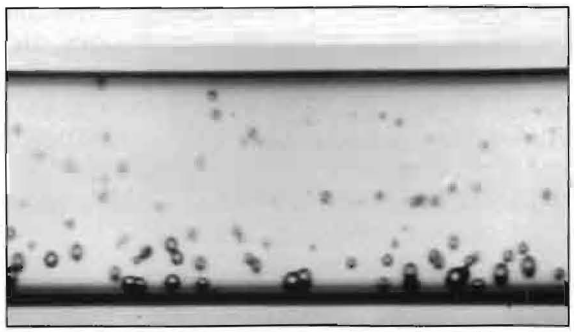


shark propulsion which included muscle activity, kinematics, and interactions between median fins. Her results demonstrate an advantageous hydrodynamic interaction between the first dorsal and caudal fins. Graduate student Peter A. Fields also used the treadmill in his studies on Pacific mackerel. These studies suggest that there is a hydrodynamic advantage for fish swimming in groups.

The research of Dr. Edvard A. Hemmingsen and graduate student Wendy L. Ryan concerns the role of hydrophobic surfaces in inducing bubble formation in blood or tissues when gas supersaturations develop in vivo. Their studies on in vitro model systems show the interface between an aqueous liquid and a smooth hydrophobic surface to be more resistant to rupture by dissolved gas than previously assumed. Thus, spontaneous nucleation of bubbles at such sites does not occur with gas supersaturations known to cause bubbles in vivo. However, when hydrophobic surfaces contain pores or other irregularities, the gas supersaturation tolerances decrease, and bubbles form readily. In such cases, bubbles originate from minute gas phases trapped in pores or crevices prior to submersion of the surfaces or are generated from dissolved gas by the liquid surface tension after the submersion.



A water droplet is placed on a layer of hydrophobic particles to determine liquid-solid contact angle.



Massive occurrence of bubbles during decompression.

E. Hemmingsen

Center for Coastal Studies

CCS

M. Clark

Wave interference patterns are studied around a tetrahedron breakwater in the Scripps wave basin.

SCIENTISTS AT THE Center for Coastal Studies (CCS) focus on worldwide coastal environments, develop data acquisition systems and research instrumentation, and advise on coastal protection and sediment management. Their studies include waves, currents, and tides in nearshore and estuarine waters; sediment transport by waves, winds, and rivers; and fluid sediment interactions. CCS research is broadly divided into three groups; shore processes, sediment management, and coastal and marginal seas.

One CCS working group is highlighted each year, this year the Coastal Engineering Research Group headed by Dr. Scott A. Jenkins is featured. This group concentrates on man's structural interventions in the coastal zone, specializing in sedimentation control, development of new breakwater and seawall shapes, and the effects of thermal and sewage outfalls in nearshore waters.

In the area of sediment management, Dr. Jenkins's group has pioneered methods for maintaining navigation depths in harbors. These methods include hydraulic jet arrays and ducted fans that periodically resuspend the bottom sediments during ebbing tide. Passive systems, such as arrays of tethered wings, resuspend sediments by the action of the trailing vortices in their wake. These systems have now been deployed as permanent installations in both Navy and private ports. The group monitors these systems to refine their design and improve their efficiency. They are aided in this design evolution process by graduate student Saima Aijaz. Her work on the strength properties of estuarine sediments has produced insights into making the existing jet array systems more effective through augmentation of salinity.

Dr. Jenkins's group also developed innovative sediment management techniques for sandy, lagunal

Geotextile-fabric covered tetrahedron prior to offshore testing as a mobile breakwater.

D. Skelly

sediments. They originated the conceptual design for the Batiquitos Lagoon enhancement. This involved increasing the tidal prism of the lagoon to the pre-1860s level and using beach grade sand that must be removed from the lagoon as nourishment for eroding beaches in Carlsbad, California. The resulting improvements to tidal circulation in the lagoon were carefully estimated using a new numerical circulation model with flooding and drying computational cells that include frictional effects.

To reduce the adverse impacts of coastal fortifications, Dr. Jenkins's group has developed new breakwater and seawall shapes having minimal reflectivity. The design concepts for these new shapes were evaluated geometries of eroding seacliffs, wavecut platforms, and coral atolls. These natural breakwaters reflect little of the incoming wave energy, a favorable characteristic for beach stability. Otherwise reflected waves radiating back to sea transport sediments down the beach slope and deposit them in offshore bars. The group's structural concept relies on parabolic, pyramidal or triangular geometries to create a special interference pattern known as Bragg reflection, whereby reflected waves are canceled by incoming waves. The concept was successfully tested on prototype scales and incorporated in a $1,000,000 seawall in California. The concept is being tested for use in a mobile breakwater consisting of large sandbags constructed of geotextile fabric in the shape of tetrahedrons. Tests on an array of tetrahedron sandbags, each measuring 3 m on a side, are under way.

Concerns over the effects of nearshore outfalls prompted Dr. Jenkins's group to develop an advection-diffusion model for the dispersion of nonconservative properties such as heat and nutrified organic particles. The heat transport models were evaluated with field data collected at the nearby Encina Power Station, where cooling water from the plant's condensers is discharged directly through the surf zone. Group scientists evaluated the balance between the shoreward directed momentum of incoming surface waves and the seaward directed momentum of the warm water outfall. They found that the distance offshore where these two fluxes balance decreases rapidly with increasing wave height, such that little outfall momentum escapes the surf zone once the wave height exceeds 1 m. Consequently the outfall scavenged little or no suspended sand from the surf zone during storm conditions when the longshore transport is most vigorous.

In collaboration with Dr. Jean A. Nichols, the group adapted the advection-diffusion model to the dispersion of sewage in nearshore waters. This problem is unusual because the concentrations of sewage particles vary not just in response to the surf zone mixing and current advection, but also in response to the consumption of particles by organisms of the food chain. In poorly ventilated coastal regions such as Santa Monica Bay, the consumption by the food chain exerts a first order control on the levels of nutrified particles in nearshore waters. Dr. Jenkins's group is now expanding this model to calculate the effects of storm drains that discharge unprocessed sewage directly across the beach into the surf zone. In this case it was observed that the highest concentrations of pathogens occur in ankle deep water where skin contact is most likely to occur. The group is now advising lawmakers on the formulation of a national beach water quality monitoring program.

Climate Research Division

CRD

Drs. Arthur J. Miller and Nicholas E. Graham collaborate on a recent tropical ocean modeling study.

SCRIPPS INSTITUTION OF OCEANOGRAPHY is playing a leading role in pioneering the interdisciplinary study of the earth as a unified system. In the newly created Climate Research Division, directed by Dr. Richard C. J. Somerville, scientists study a broad range of phenomena. These span 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. Climate change caused by human actions is the paradigm that illustrates why traditional disciplinary barriers in the earth sciences are rapidly weakening. 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.

Meteorologists and physical oceanographers in the Climate Research Division work on measuring, modeling, understanding, and predicting climate change. Their research combines the analysis of large observational data sets, the development of comprehensive numerical models of the climate system, and the exploitation of satellite remote sensing capabilities for monitoring the entire planet. They collaborate closely with other scientists at Scripps, in the California Space Institute, at the Los Alamos and Livermore national laboratories, and elsewhere. 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. Studies focus on a range of regional and global climate phenomena, including El Niño, the Indian monsoon, the Pacific Intertropical Convergence Zone, the California

Current system, and precipitation and water supply in the United States.

Dr. Daniel R. Cayan is investigating how the transfer of heat and moisture from the upper ocean is spatially organized by the atmospheric circulation. These processes are accentuated during winter, producing large-scale changes in the surface temperature fields over the North Atlantic and the North Pacific. Drs. Arthur J. Miller, Tim P. Barnett, and Nicholas E. Graham are collaborating with a German scientist on tropical ocean modeling. Their focus is the physical processes that affect heat fluxes during El Niño events. They are analyzing results from a layered numerical ocean model, constructed in constant-density coordinates, which is forced by observed wind fields. Dr. Barnett and colleagues at the Max Planck Institute have also initiated studies into El Niño-Southern Oscillation (ENSO) phenomena, using a combination of numerical model results and observational data. They are studying the physical mechanisms governing the slow eastward drift of anomalies from Asia to near the coast of South America. Based on these studies, Dr. Barnett is developing a coupled ocean-atmosphere model for ENSO prediction.

Drs. John O. Roads and Miller have collaborated on the development of a simplified coupled atmosphere-ocean model of the mid-latitude winter climate system. In the model, large-scale, air-sea interactions enhance the persistence of sea-surface temperature anomalies. Drs. Roads and Kyozo Ueyoshi are studying mesoscale simulations of the atmosphere over the western United States and adjacent portions of the Pacific. Their model has 12 layers in the vertical and a horizontal grid spacing of 256 km. Preliminary results suggest that this model can simulate climatic features that cannot be discerned from global models with coarser resolution. Drs. Roads and Ueyoshi are evaluating a medium-range weather forecasting model for precipitation prediction aimed at improving weather forecasts as they effect forest fire control. In studies of small-scale events, Drs. Ueyoshi and Roads have numerically simulated the Santa Ana wind system of southern California. Dr. Ueyoshi has also successfully modeled the orographic effects of the island of Hawaii on atmospheric eddies and rainfall.

Dr. Shyh-Chin Chen, Dr. Roads, and a colleague have developed a numerical model of the atmospheric general circulation. The model produces a realistic simulation of the variability of the tropical atmosphere. Drs. Chen and Roads are analyzing tropical and mid-latitude numerical predictability experiments. Drs. Chen and Richard C. J. Somerville have used the model to study the kinematic effect of the Himalayas on the onset of the Indian summer monsoon. Drs. Roads and Chen have also analyzed the global budget of atmospheric moisture, using observational data. They then used their analyses to validate results from atmospheric model simulations. Drs. Sam F. Iacobellis II and Somerville, have developed a diagnostic model of the coupled air-sea system and have used it to study the Indian summer monsoon onset. They find that convection during the onset depends on the horizontal advection of moisture that occurred a week earlier. Drs. Iacobellis and Somerville have also studied the feedback effects of cirrus clouds on climate change. Their theoretical results show how these feedbacks can either amplify or reduce changes caused by the greenhouse effect, depending on the microphysical and radiative properties of the clouds.

Dr. Alejandro Pares-Sierra has developed a multi-layer primitive-equation model of the northeastern Pacific Ocean. The model, which includes open boundaries and realistic geometry and topography, has reproduced the detailed statistical characteristics of the response of the California Current system to realistic wind forcing. Dr. Pares-Sierra is analyzing the energetics of the system. Dr. Benjamin S. Giese is using an ocean general circulation model to study the onset and maintenance of El Niño. He is also developing a large-scale coupled ocean-atmosphere model with which to simulate the seasonal cycle and interannual variability.

Dr. David J. Erickson III is numerically simulating the air-sea exchange of climatically important gases, including carbon dioxide, carbon monoxide, and dimethyl sulfide. He is using his calculations of the sources of these gases in numerical simulations of global atmospheric chemistry and dynamics. Dr. Erickson is also studying the response of atmospheric general circulation models to changes in soil moisture, which can strongly influence droughts in North America.

Geological Research Division

GRD

Dr. David T. Sandwell compares satellite data with bathymetric charts to identify large seamounts and fracture zones.

STUDIES IN THE GEOLOGICAL RESEARCH DIVISON (GRD) cover a wide range of scientific areas from the deep ocean to outer space. This year's report includes selected examples from the large spectrum of ongoing GRD research.

Satellite Altimetry

Over the past decade satellite altimetry has become important in studying the geology and geophysics of remote ocean areas. Spacecraft such as GEOS-3, SEASAT, and GEOSAT use pulse-limited radars, along with very accurate orbits, to measure the ocean surface topography. Because the sea surface is nearly an equipotential surface of the earth's gravity field, variations in sea-surface topography reveal variations in marine gravity. At short wavelengths (< 200 km), the topography of the sea surface mimics the sea-floor topography. Thus satellite altimeters provide reconnaissance for vast areas of uncharted sea floor such as the Southern Ocean and Antarctic margins. The geophysical applications for these data include, the location of uncharted features for planning detailed shipboard surveys and improving bathymetric charts, the identification of fracture zone trends for improving plate reconstruction models, the determination of the global distribution and loading histories of undersea volcanoes, and the location of marine sedimentary basins for hydrocarbon exploration.

Dr. David T. Sandwell is analyzing data from GEOSAT to improve accuracy, resolution, and coverage, especially in polar areas where sea ice obscures the ocean surface for much of the year. GEOSAT data were combined with available shipboard bathymetric data and magnetic anomaly identifications to construct a tectonic element chart of the Southern Ocean. The major elements, in-

Dr. Sandwell examines radar images collected by the Magellan spacecraft in orbit around Venus.

cluding seven large age-offset fracture zones, were used to place tight constraints on the early breakup of Gondwana. In many cases, onshore extensions of these major fracture zones correlate with prominent continental structures. For example, the Udintsev fracture zone extends from the northern edge of the Chatham Rise 4,500 km across the South Pacific north of Thurston Island; its onshore extension marks a major tectonic and physiographic boundary between the Weddellia and Marie Byrd Land crustal blocks of West Antarctica.

Graduate student Christopher S. Small and Dr. Sandwell have examined GEOSAT gravity profiles over sea-floor spreading ridge axes in terms of spreading rate. A global analysis shows an abrupt transition from a high amplitude gravity trough at low spreading rates, to a low amplitude gravity peak at high spreading rates. The gravity transition is more pronounced than a similar transition observed by others in bathymetric profiles. To explain these observations, Dr. Yongshun Chen developed a model of ridge-axis flow (spreading) that incorporates a realistic nonlinear, temperature and pressure-dependent rheology for both the crust and the mantle. The high temperatures at the ridge axis produce a triangular-shaped area in the lower crust that is weak relative to the overlying brittle crust and underlying mantle (decoupling chamber). The width of the decoupling chamber depends upon spreading rate, crustal thickness, and mantle temperature. When its width is less than the width of the failure zone, an axial valley develops. When the width of the decoupling chamber exceeds the width of the failure zone, the crust and mantle are decoupled and an axial high develops. This simple model explains the change in morphology of spreading ridge axes with spreading rate as well as the general roughness in the abyssal hills and fracture zones on old sea floor.

Graduate student Catherine L. Johnson and Dr. Sandwell will analyze the radar altimetry data and synthetic aperture radar (SAR) data to be collected over 90% of the surface of Venus by the Magellan spacecraft. The radar altimeter will map the topography of Venus, while the SAR provides high resolution images of the tectonic and geologic features of the crust. Venus, similar in size and composition to the earth, is thought to be a tectonically active planet. However, because of its dense atmosphere, the temperature at its crustal surface approaches the point at which rocks flow rather than fracture when subjected to tectonic stresses. Previous radar observations of Venus show that the style of tectonics on Venus is more disorganized and diffuse than the tectonics discovered in the earth's ocean basins. This may be because the strong outer surface layer of Venus (lithosphere) is hotter and thinner than the lithosphere on earth.

Ocean and Climate History

The paleoceanography group, headed by Dr. Wolfgang H. Berger, pursues research on different time scales. Their goal is to extract clues from the sedimentary record about variations in the climate and productivity of the ocean. Drs. Carina B. Lange and Arndt Schimmelmann and colleagues focus on the history of the California Current over the last several centuries. The study of laminated sediments in Santa Barbara Basin yields valuable proxies of changes in temperature, productivity, rainfall, and storminess in southern California. In collaboration with Dr. Mia J. Tegner, Dr. Schimmelmann found evidence that the organic carbon in the basin sediments carries an isotopic signal related to the amount of kelp-derived particles brought in from the shore. Thus, destruction of kelp by storms or ENSO events, or both, leaves a record that can be

recovered by careful chemical studies. Graduate student Memorie K. Yasuda has been collecting tree ring data to compare with the marine record.

In a project with Dr. Ute C. Herzfeld ocean productivity is being reconstructed from physical factors only (such as temperature, depth of mixed layer, phosphate concentrations), and the rules of such reconstruction are being applied to the ice-age ocean.

Graduate students Juan C. Herguera and Guoping Wu are using the sediments of Ontong Java Plateau, taken by box and piston cores, to study the history of the western equatorial Pacific. Their focus is on productivity changes over the last 500,000 years and on variations in the carbonate saturation of deep waters. Results so far suggest that productivity varied markedly during the Pleistocene, and that it may be possible to extract the magnitude of the variations quantitatively using benthic foraminifera. Also, there is little question that saturation of deep waters fluctuated greatly; the levels of equal preservation of calcareous fossils vary over a depth range of about 1 km.

Drs. Berger and Lange, and Wu took part in leg 130 of the Ocean Drilling Project to the Ontong Java Plateau. Dr. John A. Tarduno was in charge of paleomagnetic studies. Cruise highlights included recovery of three complete and undisturbed Neogene sections, showing substantial fluctuations in ocean productivity in that region during the last 25 million years.

Drs. William R. Riedel and Linda E. Tway developed systems to assist in gathering and interpreting paleontological and stratigraphic data. These computer programs improve the reliability and reproducibility of the data and their initial interpretation by supplying the user with expert guidance.

In an effort to improve biostratigraphic resolution and correlation between the tropics and the high latitudes, Dr. Annika B. Sanfilippo is clarifying the phylogenies of Cenozoic radiolarian taxa found in the deep-sea sediments. Once these phylogenetic relationships are known, they will provide a basis for studies of tempo and mode of radiolarian evolution through time and space. The results can be interpreted in terms of changing paleoceanographic conditions.

Mantle and Crust Processes

Dr. Devendra Lal's studies of ^3He and ^4He in diamonds continue to provide information about mantle and crust processes. Earlier studies had shown that high $^3He/^4He$ ratios, >50 x Ra (Ra = atmospheric $^3He/^4He$ ratio = 1.40×10^{-6}) in some diamonds arose from cosmic ray irradiation of diamonds in the alluvium. The ^4He concentration distribution was puzzling because a majority of the diamonds have ^4He concentrations close to about 0.5 μcc ^4He/g. In a recent theoretical paper, Dr. Lal showed that this was a consequence of ^4He implantation in diamonds during their residence in the cratons. The peaked concentration arose because most of the diamonds were emplaced in the craton about 100 m.y. ago and most analyzed are of a few millimeters in diameter. The latter factor is important because the concentration of implanted ^4He (atoms/g) depends on the size of the diamond.

The theories of the modification of ^3He and ^4He concentrations in diamonds by nuclear mechanisms were validated from studies of diamonds recovered from the "pipe," and from the alluvium in Andhra Pradesh (South India). These studies carried out by Dr. Lal in collaboration with Drs. Harmon Craig and Roger C. Wiens demonstrate unambiguously the importance of the introduction of cosmogenic ^3He in alluvial diamonds and radiogenic ^4He in pipe and alluvial diamonds.

Tracer Studies of Ocean Circulation

The group headed by Dr. Ray F. Weiss is studying trace gases in the ocean and atmosphere. They are using the dissolved atmospheric chlorofluorocarbons (CFCs or "freons") F-11 and F-12 as inert time-dependent chemical tracers to study the deep ocean circulation. Concentrations of these man-made compounds have been increasing steadily in the atmosphere, and hence in the surface waters of the world ocean, since their first production in the late 1930s. With the advent of sensitive shipboard gas chromatographic techniques (detection limit about 1 gram of CFC per cubic kilometer of seawater), these compounds have become useful tracers of the rates of formation, transport and mixing of subsurface waters where such processes take place on a time scale of decades.

Group researchers have traced the deep waters of both Arctic and Antarctic origins into the equatorial region through six years of participation in several Atlantic Ocean expeditions. In the deepest waters, Lower North Atlantic Deep Water and Antarctic Bottom Water form well-defined western boundary currents, which have been traced by their CFC concentrations to within about 5° of the equator. The apparent "ages" of both of these waters in the equatorial region, based on their F-11/F-12 ratios,

are about 30 years. There has been substantial dilution of the CFC-bearing source waters by subsurface mixing.

Based on CFC measurements in 1982-1983, Upper North Atlantic Deep Water (UNADW) was found to have propagated along the western boundary from its northern source region. The UNADW reached the equatorial region at a depth of about 1,700 m with an apparent age of about 25 years and an apparent 5-fold dilution. Subsequent CFC measurements in 1987-1988 showed that the UNADW western boundary transport divides at the equator, with one limb extending eastward along the equator to at least the prime meridian, and the other limb continuing along the western boundary into the Southern Hemisphere. The rates of propagation of these features, as given by the observed changes in the distribution of detectable CFC concentrations over the 5-year measurement period, and confirmed by the differences in apparent ages, are about 2 cm/sec eastward along the equator, and about 1 cm/sec southward along the western boundary.

Antarctic Intermediate Water (AAIW), as shown by its CFC distributions, moves northwestward around the anticyclonic subtropical gyre of the South Atlantic reaching the equator at the western boundary. Most of the AAIW crosses the equator to form a western boundary flow in the North Atlantic, but there is also significant eastward AAIW propagation along the equator.

Such observations provide chemical and physical oceanographers with unique information on the pathways and rates of "ventilation" of deep ocean waters. This contributes to the verification of numerical models of deep ocean circulation and to an understanding of the uptake by the deep ocean of other environmentally important anthropogenic atmospheric trace gases such as carbon dioxide.

The Role of Fluids in Convergent Plate Margins

Convergent plate margins are typified by large-scale fluid fluxes, enhanced fluid-solid (sediment and rock) reactions, (consolidation and deformation) and by perturbation of the geothermal regime. Extensive venting of fluids manifested by dense benthic communities and/or mud volcanoes, was recently documented from several convergent plate margins, for example, off the Oregon-Washington coast, seaward of the Barbados Ridge and Japan Trench.

Drs. Miriam Kastner and Joris M. T. M. Gieskes participated in an Ocean Drilling Program expedition to the Nankai Trough (off southern Japan) convergent plate margin. For the first time program scientists were successful in penetrating the overriding plate and into the subducting plate. The most distinctive characteristic of the fluid chemistry in the central Nankai Trough is the low Cl^- concentration at the level of the décollement. The minimum measured value indicates an approximately 20% dilution of seawater. In this geologic setting, the most probable processes to produce low Cl^- fluids are clay mineral dehydration and membrane ion filtration caused by one of two processes. First is a major pulse of low Cl^- fluid along the décollement, originating deeper down in the thicker and more extensively deformed landward sediment reactions. The second process is in situ production by the above reactions at temperatures above 60°C. Preliminary diffusion-advection calculations imply that the first scenario should have occurred more than 3×10^5 years ago; the in situ production possibility would require dewatering of more than 20 weight % smectite. This amount of smectite is not available at the site drilled.

No direct evidence of past or present channelized fluid flow was found, not even along the young major thrust fault, at ~365 m below sea floor, which extends to the décollement. This, however, does not preclude past pervasive fluid movement through the sediment or active advection of the interstitial waters at rates slow enough to allow diffusive processes to dominate the concentration-depth profiles. An active leaky décollement is consistent with the pore pressure profile.

Development of Ocean Bottom Seismographs

During the past year Dr. LeRoy M. Dorman and Allen W. Sauter conducted tests in Buzzard's Bay, Cape Cod, of the new Ocean Bottom Seismographs being constructed in collaboration with three universities. The trials included "pull tests" in which divers applied force steps of controlled magnitude to simulate steps functions in ground acceleration. These tests are necessary for clarifying the coupling between the seismic sensors and the soft sea floor.

Marine Biology Research Division

MBRD

Dr. Mark E. Huntley examines copepods in a study of the ecological energetics of Antarctic zooplankton.

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 function of neurons in the electorsensory system of gymnotiform fishes, the population dynamics of Antarctic zooplankton, and the symbioses of chemoautotrophic bacteria with marine invertebrates from various environments.

Scientists in Dr. Douglas H. Bartlett's laboratory found that some deep-sea bacteria sense and respond to changes in hydrostatic pressure by modulating protein production and gene expression. This sensory response may be unique to abyssal organisms. The gene for one deep-sea bacterial protein, whose production is regulated in a barometer-like fashion, has been cloned and sequenced. The deduced amino acid sequence is similar to a class of proteins forming diffusion channels across the outer membrane of bacteria. How and why this and other proteins of deep-sea bacteria are regulated by pressure is currently being explored at the molecular level.

Dr. Horst Felbeck's group studies the symbiotic relationship between chemoautotrophic bacteria and marine invertebrates from hydrothermal vents and other environments. The bacterial symbionts live inside cells of specialized host tissues and supply organic material as a nutritional supplement. The bivalves and worms harboring these bacteria normally have either a reduced digestive system or no trace of a gut, mouth, or anus. Dr. Daniel L. Distel identified bacterial symbionts from several sources by sequencing their 16s ribosomal RNA. Graduate student Jeffrey L. Stein sequenced the gene for the enzyme ribulose bisphosphate carboxylase from a deep-sea bac-

Members of Dr. Huntley's field research team prepare a MOCNESS (multiple opening-closing net and environmental sampling system) for field sampling.

W. Nordhausen

terium symbiotic with a gastropod. This is the first time an enzyme from a deep-sea organism has been completely characterized on the molecular level. Dr. Distel expressed the gene in *E. coli* and plans to describe the enzyme biochemically. Graduate student Ute Hentschel is investigating pathways of nitrogen acquisition in the symbiotic system. She has detected the ability of the symbionts to respire nitrate anoxically.

Dr. Victor D. Vacquier's group studies the mechanism of sperm-egg interaction during sea urchin and abalone fertilization. They are interested in the abalone sperm protein lysin that makes a hole in the egg envelope. Group researchers have cloned and sequenced the gene for this protein from several species, and they are determining the sequence differences of the California species to see how the protein evolved. The proteins involved in the induction of the acrosome reaction of sea urchin spermatozoa are also being studied.

Scientists in Dr. Benjamin E. Volcani's group are investigating the mechanisms by which silicon regulates gene expression and DNA replication in diatoms. Currently, they are studying two native plasmids, pCf1 and pCf2, from the diatom *Cylindrotheca fusiformis*. Dr. Mark M. Hildebrand and collaborators completed the nucleotide sequence determination of pCf1, which contains five open reading frames. Comparison of the sequences of pCf1 and pCf2 has resulted in the identification of one open reading frame shared by the two plasmids as a homolog of a class of proteins called resolvases. Resolvases have been found only on transposons, and this and other data suggests that pCf1 and pCf2 act as mobile genetic elements in the cell.

Researchers in Dr. Mark E. Huntley's laboratory focus on several areas. They study the population dynamics and ecological energetics of Antarctic zooplankton as part of the interdisiplinary RACER (Research on Antarctic Coastal Ecosystem Rates) program. Dr. B. Gregory Mitchell and the

group observed the effect of zooplankton grazing on bulk optical properties of seawater. This mesocosm study was conducted in the Scripps deep tank. Dr. Maria Vernet collaborated on a laboratory study of the biochemical fate of chlorophyll-*a* after ingestion by zooplankton. Graduate student Paul F. Sykes is investigating the chemical ecology of copepod-dinoflagellate interactions, including a demonstration of the learning and memory processes in copepods. Graduate student Mai D. G. Lopez is observing the effects of food supply variability on copepod larval development, and she is working on trophodynamic studies of microzooplankton. Graduate student Walter Nordhausen has described the life cycle of the Antarctic euphausiid *Thysanoessa macrura* and is now studying its population dynamics.

Dr. Kenneth L. Smith is studying the ecological energetics of deep-sea benthic boundary layer communities. Long time-series measurements (> 2 years) of benthic boundary layer processes are now under way at a 4,100-m-deep eastern North Pacific station. Particulate organic matter flux (food supply) entering the benthic boundary layer is compared with activity rates of near-bottom animals. These animals are monitored with an acoustic array; the benthic organisms are monitored with time-lapse cameras and a sediment respirometer. Smith's preliminary results show a strong summer signal in the input of particulate organic matter into the benthic boundary layer. The seasonal patterns of scavenging grenadier fish at this station are also evident from acoustic tagging experiments conducted in a collaborative study. The energetics and sensory biology of another dominant group of scavengers in the deep sea, lysianassid amphipods, are being studied by graduate student Ronald C. Kaufmann. Graduate student Waldo W. Wakefield is studying the spatial and seasonal distribution patterns of demersal and benthic megafauna at slope depths.

Dr. George N. Somero's group focused on the biochemical and molecular changes facilitating tolerance and exploitation of diverse marine environments. Graduate student Elizabeth P. Dahlhoff discovered that enzyme adaptations to elevated temperatures, as well as high pressures, are instrumental in allowing hydrothermal vent fishes and invertebrates to withstand these elements in their habitats. Her data suggest that only some of the vent invertebrates, notably the polychaete "Pompei worm" *Alvinella pompejana*, can tolerate high temperatures. Graduate student Sandor E. Kaupp concentrates on the biochemical concomitants of larval development in various marine fishes. He developed biochemical indices of growth rate, and resting and active metabolism to estimate the physiological status of field-collected fish.

Dr. Allen G. Gibbs completed work on the ion-regulatory enzyme, Na^+-K^+-adenosine triphosphatase (Na-K-ATPase). This enzyme exhibited a large decrease in activity in deep-sea species, suggesting that these sluggish fishes have low monovalent ion regulatory costs. Adaptation of the Na-K-ATPase to high pressures was shown to be caused by adaptive changes in the protein and lipid moieties of this membrane-associated enzyme. Graduate student Tzung-Horng Yang studied the metabolic and biochemical properties of *Sebastolobus alascanus*, a fish common in the oxygen minimum layer. He showed that they have a low metabolic rate and a remarkable ability to extract oxygen from seawater.

Dr. Mary Sue Lowery examined the abilities of the enzyme phosphofructokinase to bind to the contactile filaments of fish locomotory muscles. She found striking differences among fishes and muscle types related to phylogeny and locomotory activity. Dr. Anne E. DeBevoise studied the effects of pressure and temperature on the enzyme pyruvate kinase from hydrothermal vent organisms from the tropical eastern Pacific and the Pacific Northwest.

Dr. Andrew A. Benson studied algal and sea grass productivity during a cruise in the Indian Ocean near the Republic of Seychelles. The algal and plant sulfolipid, a chloroplast membrane detergent-type lipid isolated in Dr. Benson's laboratory, is being investigated by National Cancer Institute scientists for activity against the AIDS virus.

Dr. Lanna Cheng studied *Prochloron*-didemnid symbioses and algal biotechnology. She and Dr. Ralph A. Lewin organized an expedition to Belau, Micronesia, to study nitrogen metabolism and other aspects of the symbiotic system. Dr. Cheng was technical advisor to a United Nations project in the Peoples' Republic of China. The program objectives are to extract beta-carotene from the brine alga *Dunaliella*, to produce *Artemia* biomass and dry cysts for mariculture, and to improve the quality and quantity of salt production. Dr. Cheng continues her *Halobates* research.

The species of green algal flagellates that Dr. Lewin has recently isolated show a remarkable diversity of physiological and biochemical features, and some are currently being screened for biotechnological uses. Some species of *Dunaliella*,

capable of growing in almost saturated brine, produce beta-carotene, which is used as a food colorant and may be a potential anticancer agent. Dr. Lewin visited a number of Chilian laboratories where *Dunaliella* cultivation is being studied. He made a short expedition to collect new strains from saline ponds in the Atacama Desert of Chile. Also being looked at for biotechnical use are some *Chlamydomonas* species that can deposit calcium phosphate (brushite), something not hitherto reported for any alga.

Dr. Joan G. Stewart completed a work on marine algae and seagrasses of San Diego County, detailing distribution and describing morphology. This information was collected from intertidal and subtidal ecological studies over recent years. Comparisons of seasonal and annual fluctuations of algal populations in selected sites continue to elucidate the larger scale biogeographical patterns.

Drs. Amir Neori and Francis T. Haxo developed a procedure to estimate the contribution of accessory pigments to algal photosynthesis. The procedure uses an oxygen electrode and three light beams. The method aids in identification of minor pigments' funtion. The procedure may be used in the field to estimate photosynthetic enhancement in phytoplankton populations exposed to natural light.

Dr. Walter F. Heiligenberg and collaborators continue research on the structure and function of neurons in the electrosensory system of gymnotiform fish. They concentrate on sensory-motor integration and the development of the lateral line. Studies on the pacemaker nucleus, which triggers electric organ discharges, show that it is innervated by different types of diencephalic prepacemaker neurons. These neurons drive different forms of pacemaker modulations, which serve as signals in social communication. By using specific blockers they demonstrated that the modulations are mediated by different glutamate receptor subtypes within the network of the pacemaker nucleus. The same network of neurons can thus be driven to generate different output patterns. Studies on electroreceptors' and mechanoreceptors' development showed that the formation of receptors is induced by the presence of primary afferent fibers that invade the epidermis of the larva.

Dr. William A. Newman and colleagues continue work on West Pacific barnacles taken from bathy-abyssal hydrothermal vents. The barnacles provide a glimpse of a Late Mesozoic relict fauna replaced elsewhere in the ocean by modern forms. They include at least two new genera related to *Neolepas* (the most primitive living scalpellomorph from vents at 21°N off Mexico) and *Neoverruca* and *Eochionelasmus* (the most primitive verrucomorph and balanomorph respectively). An extant representative of the U. Triassic Brachylepadomorpha, a suborder thought to have become extinct in the Miocene, is also under study. Graduate student Robert J. Van Syoc continues his work on purification and sequencing of barnacle mitochondrial DNA. He reported that a barnacle thought extinct (Mio-Pliocene) in the ancient headwaters of the Gulf of California, is not only living in the region but is identical to the relatively rare *Balanus subalbidus* of the West Atlantic.

Dr. George D. F. Wilson has led two expeditions to study the deep benthos of manganese nodule-covered regions. Scientists sampled a nodule mining reserve area during the multi-national cruise aboard University of Hawaii's R/V *Moana Wave*. Researchers on a R/V *New Horizon* expedition used the Remote Underwater Manipulator (RUM) III to collect precisely positioned samples from 4,500-m-deep microhabitats, which had been disturbed by a test mining device in 1978. Dr. Wilson successfully detailed the internal genital morphology of isopods using histological techniques including microwave fixation. He and graduate student Michel A. Boudrias have reported on a unique swimming mode in the deep-sea isopod genus *Munneurycope*. Dr. Wilson and a San Diego Natural History Museum colleague investigated the evolution of the isopod suborders.

Marine Life Research Group

MLRG

Peter B. Edwards and undergraduate Kristin L. Riser measure sea urchins before returning them to the ocean as part of ecological studies of the Point Loma kelp forest community directed by Drs. Mia Tegner and Paul Dayton.

SCIENTISTS IN THE MARINE LIFE RESEARCH GROUP (MLRG) study the physics, chemistry, biology, and meteorology of the California Current system and its environs. MLRG researchers embarked upon six expeditions in the California Current region during the year. Four of these cruises were part of the California Cooperative Oceanic Fisheries Investigations (CalCOFI) program. Through this cooperative program data have been collected from the California Current region for forty years. Vertical sections of conservative properties taken across the current during the last year (June 1989 - July 1990) show that it did not vary significantly from long-term mean conditions.

Working aboard CalCOFI cruises, Dr. Michael M. Mullin has measured the production of eggs by the abundant zooplanktonic copepod, *Calanus pacificus*. He is determining its seasonal and geographic patterns of reproduction in comparison with the distributions of temperature and the copepods' phytoplanktonic food. The reproductive rate tends to be high (30 eggs/female/day) in the Santa Barbara Channel and in the waters overlying the Santa Rosa-Cortes Ridge. On the western edge of the California Current, the few females present were so malnourished that food had to be supplied for 1 - 2 days before they started laying eggs. The regions of strong reproduction were more extensive in winter and spring than in summer and fall, but some eggs were produced year-round.

Dr. Mark D. Ohman has developed a method to study zooplankton predator-prey interactions. He uses polyclonal antibodies to detect planktonic ciliates in the gut contents of suspension-feeding copepods. This assay makes it possible to investigate ciliate-copepod interactions in the sea without introducing the artifacts of traditional collection and incubation methods. In these controlled ex-

periments, Dr. Ohman found that the copepod, *Calanus pacificus*, has different rates of predation on two common genera of ciliates, *Strombidium* and *Uronema*. These two ciliate genera manifest markedly different growth rates when raised on planktonic bacteria. These results suggest that the importance of the food-web link from bacteria to ciliates to copepods is markedly dependent upon the species composition of a ciliate assemblage.

Microbial transformations of the particulate and dissolved organic carbon (POC and DOC) in the water column are being studied by Dr. Angelo F. Carlucci and associates. This study is part of an interdisciplinary, multi-institutional program on fluxes of sinking POC and DOC. Using dissolved free amino acids (DFAA) as microbial tracers, they observed rapid transformations of both POC and DOC into bacterial biomass. Furthermore, the microbial populations "repackaged" the POC into forms that can be consumed by organisms higher in the food chain. As expected, the greatest microbial activity was in euphotic zone waters and the least in intermediate depth waters. Waters above the bottom showed microbial activities nearly comparable to the upper waters. A recent observation was that a major source of DFAA is dissolved, combined amino acids, probably peptides.

Several physical and biological oceanographers from MLRG are studying the Ensenada Front, where the cold, rich California Current impinges upon warm, less rich water from offshore. This produces a frontal region characterized by sharp spatial gradients of sea surface temperature and chlorophyll that are clearly evident in satellite images. Dr. Thomas L. Hayward examined the mesoscale distribution of oceanographic properties in the vicinity of the Ensenada Front. His observations verify the strong effect of ocean circulation on near surface nutrient distributions, which, in turn, regulate primary production in this region. This study is part of a larger investigation in which he is comparing the effects of offshore eddies and fronts to other processes (such as coastal upwelling) that affect primary production in the California Current.

As part of the same study, Drs. Pearn P. Niiler and Theresa K. Chereskin used data from drifter clusters deployed in diamond patterns on 10 km separations to estimate the vorticity and divergence field along the Ensenada Front. These estimates indicate a pattern of divergence and upwelling in the center of the shoreward-flowing frontal jet, and convergence downwelling at its edge. The vertical velocity magnitude of a few meters per day is small compared to horizontal velocities of 0.5 m/sec, but important because vertical pumping can change the nutricline depth and hence directly affect primary productivity.

Dr. Elizabeth L. Venrick compared the phytoplankton to the south of the Ensenada Front with the phytoplankton from a study site in the North Pacific Central Gyre. She found that the species structure and vertical distribution patterns at the southern edge of the Ensenada Front are statistically indistinguishable from those of the North Pacific Central Gyre. This was so even though the distance between the "center" and eastern "edge" of the Central Pacific Gyre exceeds 3,150 km. The similarity of phytoplankton assemblages is quantitative evidence of the extent and homogeneity of the Central Pacific ecosystem.

Dr. Loren R. Haury and a colleague are studying the effects of seamounts on the surrounding ocean environment. Their work at Fieberling Guyot, 915 km west of San Diego, examined the hypothesis that zooplankton patchiness is intensified over and around seamounts because of the interaction of the plankton and currents with the seamount. Early results suggest that zooplankton abundance can be reduced over the seamount when the plankton migrate up in the evening from below the depth of the seamount summit. This area with reduced numbers is then carried away from the seamount to increase patchiness in the surrounding regions.

Drs. Mia J. Tegner and Paul K. Dayton continued long-term studies of the ecology of kelp communities. Recent work focuses on how gradients in light and temperature, associated with depth, affect reproduction of the major species of kelp in the large Point Loma kelp forest and, ultimately, the response of the algal community to disturbance. Clearings were established at three depths (8 m, 15 m, and 21 m) and growth and reproductive rates of the three major kelp species were followed under conditions of intra- and inter-specific competition. The results indicate that the giant kelp (*Macrocystis pyrifera*), which is by definition the climax species in this community, is also a superb opportunist; it "won" the competition at each depth under unmodified conditions. Only when *Macrocystis* densities were experimentally reduced were the other kelp species able to reproduce effectively. The results underline the importance of disturbance to *Macrocystis* populations for the establishment and continuance of the lower-standing kelp species.

Dr. James J. Simpson is developing and testing

Peter Edwards and Kristin Riser load boat before leaving for the Point Loma kelp forest (off San Diego).

improved algorithms for the extraction of geophysical and biological variables from remotely sensed data. These include more accurate cloud-detection and cloud-removal procedures, improved plant-pigment detection, automated computation of near-surface velocities, and the computation of flow components.

Joseph L. Reid has been studying the circulation of the North Atlantic Ocean, which contains several layers of water with different sources and characteristics. These characteristics can serve as tracers that identify the sources and the paths of spreading within the ocean. From these studies he concluded that cold waters at the bottom of the North Atlantic have entered from the Antarctic. Above this, a layer of warm, saline water, formed within the North Atlantic flows southward, and above this, at about 100 m, a thinner layer of water from the Antarctic moves northward. He also found that the mid-depth flow is not entirely of North Atlantic origin, but that a portion entered from the Antarctic Circumpolar Current, and spread northward, east of the mid-depth southward flow.

Drs. Chereskin and Dean H. Roemmich have confirmed, by direct observation, one of oceanography's oldest theories about wind-driven circulation. Using acoustic Doppler current profilers and geostrophic measurements, they were able to extract wind-driven, upper-ocean flow. They found agreement between the measured transport and the transport inferred from both shipboard and climatological winds. A surprising result was that wind-driven transport extended about 100 m down–deeper than previously estimated and below the mixed-layer depth–thus affecting previous heat transport calculations.

California Space Institute

CSI

Dr. Alejandro Pares-Sierra studies his models of the California Current system.

THE UNIVERSITYWIDE CALIFORNIA SPACE INSTITUTE (Cal Space), under new director Dr. Sally K. Ride, continued its commitment to education, its mini-grant program, and in-house research. Cal Space's involvement in space science education was enhanced when NASA designated the Cal Space-led consortium (UC San Diego, Los Angeles, and Berkeley) as a 'Space Grant College'. With the designation came money for curriculum development and graduate fellowships in space-related fields. Cal Space also began a cooperative educational program with the Jet Propulsion Laboratory for advanced graduate students and undergraduates.

Cal Space supports space and earth science research through its mini-grant program that distributes small research grants to investigators from all UC campuses. Last year 40 investigators were awarded a total of $604,000. These funds serve as seed money to support researchers and graduate students in astrophysics, space science, satellite remote sensing, and space technology.

Cal Space researchers address global change studies and space science. Cal Space scientists apply satellite remote sensing and numerical modeling techniques to study fundamental questions of climate and global change caused by both natural and anthropogenic forces. Several examples of ongoing Cal Space research activities follow.

Dr. Alejandro Pares-Sierra constructed a model of the California system, forced by observed winds, that is used to simulate the upper layer thickness and surface currents of the northeastern Pacific Ocean. The model is used to test important hypotheses about the El Niño/Southern Oscillation such as whether the observed California-tropical El Niño co-occurrence is caused by an atmospheric or oceanic teleconnection. With the model, Dr. Pares-

Sierra has demonstrated the importance of remotely generated variability in the California Current system's energy budget. A schematic path for energy of large-scale variability in the current has been established through numerical simulation. This "path" is controlled primarily by linear wave dynamics; however, a non-linear element is also present. A series of incrementally more complex models has been developed in an effort to clarify this unpredictable component of the current, and to create a mesoscale forecasting model.

The present prototype is capable of becoming baroclinically and barotropically unstable, in conjunction with an 8-layer quasi-geostrophic model, and is being used to further investigate the dynamics that control the California Current. Dr. Pares-Sierra has been studying the energy path of the system, from its insertion at the surface by the wind to its dissipation by friction presumably at the ocean bottom. Preliminary analysis of the energy balance equations associated with the model have permitted the identification of preferred instable areas where energy is released from the mean flow to the eddies. The stability analysis of the modeled data aided in identifying baroclinic instability and direct wind forcing as important mechanisms for generation of mesoscale variability in the current.

Dr. Lucy-Ann McFadden uses remote sensing techniques to study the physical properties of small solar system objects (asteroids and comets) and their relationships to each other and to meteorites. In May 1990 Comet Austin (1989c1) made its closest approach to earth as it passed through the inner solar system for the first time. Dr. McFadden, in collaboration with colleagues, used a two-dimensional, thermal infrared array camera to map the spatial distribution of emitted radiation from the comet. The observations were made at the Mount Lemmon Infrared Observatory in Tucson, Arizona. Seven days of data were collected over a nine-day interval. The changes in the coma morphology were monitored at a spatial resolution of hundreds of kilometers, the highest spatial resolution ever measured for a comet in this spectral region. Thermal emission in the 10-μm region consists of emitted radiation and emission from silicate grains. The analysis of these data in conjunction with simultaneous measurements made in the visible and near-infrared spectral regions enable study of the relationship of emitted radiation to dust and gas distributions and to the distribution of silicate grains and organic grains in the comet's coma.

Dr. Robert J. Frouin is investigating a warm, salty surface current that follows poleward along the Iberian Peninsula during winter. According to satellite infrared images and hydrographic data, the current, which flows over 1,500 km, is 25-40 km wide, is approximately 200 m deep and characterized by velocities of 0.2-0.3 ms^{-1}. The current's associated geostrophic volume transport increases from about 300 x 10^3 m^3 s^{-1} near 38°3'N to 500-700 x 10^3 m^3 s^{-1} at 41°-42°N. The origin of this poleward flow and the causes for its increasing transport off western Iberia are not yet understood. Onshore Ekman convergence induced by southerly winds along the Portuguese west coast provides about one-fifth of the computed transport in the correct sense.

A mechanism that gives better quantitative agreement with the observations is the geostrophic adjustment of the eastward oceanic flow. This flow is driven by the large-scale baroclinic pressure gradient in the western North Atlantic as it reaches the continental slope of the western Iberian Peninsula. Why, in that case, is a southward coastal current consistently observed off Portugal during summer? Presumably, because the large-scale meridional pressure gradient is present all year long, one would expect a northward current. Does the southward wind stress in the region during summer prevent any northward current from developing? A meridional sea-surface tilt may also occur along the North Atlantic boundary, leading to a poleward barotrophic current. "Dam-break" type mechanisms, corresponding to the sudden release of lighter fluid over the denser quiescent layer against a rigid boundary, could indeed be triggered by the relaxation of the northeasterly wind at the end of fall. This would allow warm, light waters to flow toward the Portuguese coast and then proceed northward as a geostrophic gravity current. Many questions, in addition to these regarding the current's origin, need to be addressed.

Institute of Geophysics and Planetary Physics

IGPP

Scientists from around the world gather at Scripps for a receiver training session before the Heard Island Experiment.

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 numerous fields from seismology to underwater acoustics; in this report two selected research areas on very different topics are discussed.

Crustal Deformation: Detection and Modeling

The famous San Andreas Fault in California is associated with intense seismic activity caused by the north northwest motion of the Pacific Plate relative to the North American Plate. Strictly speaking, the Pacific Plate should include that part of California west of the San Andreas Fault that runs from Cape Mendocino to the Gulf of California. However, deformation and seismic activity are not limited to a single fault. The system of active faults in southern California is 300 km wide and ranges from the borderland province off the shore to the eastern edge of the Salton Trough. This deformation is complex and includes more than the offsetting of features across the main and subsidiary faults of the San Andreas Fault system. In some areas crustal compression leads to mountain building, as in the Transverse Ranges. Extension of the crust in other areas–the northern extension of the Gulf of California (the Salton Trough), for example–is another manifestation of the plates' interactions.

The crustal deformation pattern within this region can be characterized as crustal blocks that are separated by faults. The constant movement of

these blocks relative to each other (driven by the global plate motions) is accommodated along their boundaries (faults) causing earthquakes. Elucidating the nature of these crustal block motions and their relation to the large-scale plate motions is vital to understanding earthquake patterns in southern California.

IGPP investigators have been involved in several projects studying crustal deformation in southern California from different viewpoints. Recently Drs. Y. John Chen and J. Bernard Minster have examined a simple mechanical model to investigate regional crustal movements in this area. The region around the "Big Bend" of the San Andreas Fault is particularly complex. There the fault curves around the Mojave Desert and forms a 150-km offset along its trace. It separates the mountains in the Transverse Ranges to its west and southwest from the largely aseismic high, undeformed topography of the Mojave Desert to its east and northeast.

The model predicts the shape of the San Andreas Fault near the Big Bend surprisingly well. They interpreted the Mojave block as an analogue to the non-deforming dead metal zone found in metallurgical processes. Drs. Chen and Minster concluded that the major dextral faults in southern California, including the San Jacinto, Elsinore, and Newport-Inglewood faults, result from the snowplowing of the eastern margin of the Pacific Plate by the strong quasi-rigid Sierra Nevada-Great Valley block.

Future research will focus on modeling detailed crustal deformation within southern California and will also include vertical deformation (mountain-building process). The 3-D model requires using the San Diego Supercomputer.

Two other ongoing projects also are aimed at elucidating deformation of the earth's crust in southern California. One is to measure displacements of a few millimeters occurring over hundreds of kilometers with a set of satellites comprising the Global Positioning System (GPS). Dr. Yehuda Bock heads the group installing a network of continuously operating GPS receivers that will provide accurate constraints on the kinematics of crustal deformation within southern California. Comparison of the models and GPS data will create a more reliable picture of regional crustal deformation.

A second project focuses on more local deformation in southern California. Work at Piñon Flat Observatory includes monitoring micrometer-level displacements over baselines hundreds of meters long using laser interferometry. This off-campus facility has been incorporated into the GPS network, providing a link to the deformation mechanisms acting on different length scales.

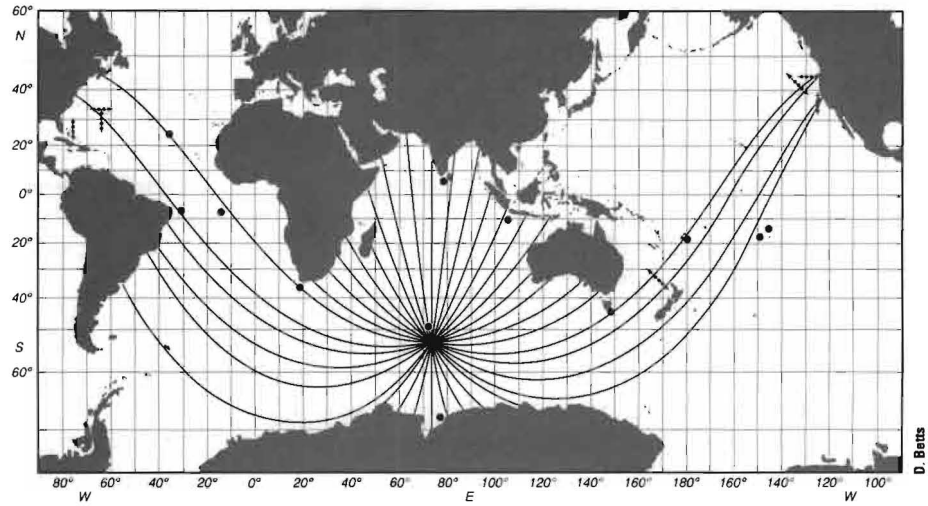
These efforts are crucial to understanding the earthquake process. Scientists hope additional knowledge of the processes involved in crustal deformation will allow the accurate prediction of earthquakes.

Several IGPP investigators are collaborating with a group of Scripps scientists in extending crustal deformation studies to submarine environments. A number of underwater geodetic instruments are being developed, including two types of tiltmeters. A short baseline tiltmeter was built to fit inside the Scripps ocean bottom seismometers (OBS). Six of these tilt-OBSs were successfully wet-tested off the U. S. east coast and are now ready for deployment. A 500-m-baseline two-fluid tiltmeter was constructed and is currently being readied for temporary installation at the Piñon Flat test facility. Tiltmeters, especially when employed in combination with seismometers, can play a major role in forecasting volcanic eruptions. These techniques will aid in establishing mid-ocean ridge volcano observatories, and in forecasting the particularly devastating shallow submarine eruptions of island arc volcanoes.

Global Ocean Warming: Detection by Long-Path Acoustic Travel Times

In recent years, the understanding and modeling of global warming caused by the greenhouse effect has been in the spotlight. A group led by Drs. Walter H. Munk and Peter F. Worcester has plans to monitor global warming by sensing the gradual rise in the earth's oceans using acoustics. The researchers became aware of a 1960 experiment in which 140 kg of dynamite were detonated in the sound channel off Perth, Australia. The explosion was clearly recorded by Bermuda hydrophones halfway around the earth.

The original experiment was interpreted as a transmission along the unimpeded oceanic great-circle route between Perth and Bermuda. Scripps researchers recently asked the question whether neglect of lateral refraction and of the earth's ellipticity was justified. Accordingly, they constructed a set of refracted geodesics radiating out of the shot site. Surprisingly, the north-south temperature gradient associated with the Antarctic Circumpolar Current deflects the rays to the left south so severely that they never make it to Ber-



Map of the predicted acoustic paths radiating from Heard Island during the experiment. Dots represent the receiving stations.

muda; the island lies in the geometric shadow. It is not clear what scattering process was responsible for putting enough energy into the shadow zone for the explosions to be heard at Bermuda.

Dr. Munk and co-workers plan to proceed with a modern version of this experiment, and they have found a source site farther south, with unimpeded access to Bermuda. They expect that this will provide a way of measuring global ocean warming. The speed of sound increases with temperature, and accordingly, the travel time between fixed points would diminish as the ocean warmed.

Four questions must be answered for the experiment to proceed successfully. First, what is a good site? After many tries Heard Island (Australia) in the Indian Ocean was chosen. Not only is there an unimpeded refracted geodesic to Bermuda, but there appears to be a path eastward through a Polynesian window to San Francisco and a Tasman Sea window to Coos Bay, Oregon. Thus, a suitable source at Heard Island could be received on both sides of North America. The site has access to all the major ocean basins, the North and South Atlantic, the North and South Pacific, the Indian Ocean and its adjoining sector of the Antarctic Ocean. It is the most ambitious site, deliberately chosen to bracket the problem of what can be done with global ocean temperature soundings.

The second question is how big is the signal? The researchers estimate a greenhouse-induced decrease in travel time of 0.2 to 0.5 seconds per year. In Scripps tomographic work a precision of 1 ms at 1,000 km range is routinely obtained. The third question is how big is the geophysical noise? This is more difficult. An estimate of 0.5 s from global mesoscale activity, and possibly larger fluctuations from basin scale variability, has been obtained.

The last question is does this experiment require explosive sources (as in 1960)? No, it is believed that existing, low-frequency, electrically driven sources would do. Physical oceanographers from Scripps and other institutions are planning a feasibility test. This involves one week of transmission from a ship-suspended source monitored from several sites including off Bermuda, the North American West Coast, New Zealand, and Tasmania. If successful, a permanent offshore installation would be connected by cable to Heard Island, and the transmission received at two to three dozen sites in all five ocean basins. Probably ten years will be required to measure the warming trend.

Initially, the time series of acoustic travel time would be used to check on the validity of the numerical models. Each source-to-receiver path is essentially a long line-integral of temperature Θ within the ocean volume, $I = \int \Theta(x,y,z)ds$. The acoustic time series yields $I(t)$. If model and measurements agree, then the model prediction gains respectability as a basis for planning. If they disagree, then the discrepancy will be found and the model improved.

The proposed experiment then serves as a classical assimilation experiment. It is not an application of ocean acoustic tomography, which consists of a sufficient network of ray paths so that travel times can be inverted to yield $\Theta(x,y,x)$ quite independent of any theory or modeling effort. An augmentation of the Heard Island experiment, which would in fact be invertible to yield temperature change with gyre or basin resolution, is being considered.

Institute of Marine Resources

IMR

THE UNIVERSITYWIDE INSTITUTE OF MARINE RESOURCES (IMR), headed by Acting Director William H. Fenical, 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. Some of these Scripps projects funded by Sea Grant are discussed below.

Drs. John A. McGowan and Michael M. Mullin have been examining the long-term impact of sewage discharge on four important aspects of water quality: temperature, light transmissivity, dissolved oxygen, and secchi disk depth. They are analyzing data collected by monitoring agencies over 15 or more years, with weekly or monthly frequencies. The data were collected near the sewage outfalls of Santa Monica Bay, Palos Verdes, and Point Loma, as well as at stations far from the outfalls.

Dr. Robert L. Guza initiated a project to test the hypothesis that the complex and variable patterns of wave energy within the Southern California Bight are predictable from an "inverse-theory model," combining wave refraction theory and limited numbers of wave observations.

Dr. Victor C. Anderson has been exploring the possibility that the geothermal resources of hot vent fields in the ocean may equal or exceed the energy resources of offshore oil reserves. The specific objective in his Sea Grant-funded project is to develop an autonomous instrument package that will make a year-long profile of the temperature and velocity of the plume of very hot "black smoker" vents.

Dr. Jules S. Jaffe is fabricating polymer acoustic sensing arrays for use in the ocean. He is developing a basic acoustic tool for observing oceanographic phenomena at high resolution and fast frame rates.

Dr. Toyoaki Nogami is examining design considerations for waterfront sheet-pile walls that will minimize damage to these structures during earthquakes.

Dr. Richard J. Seymour is conducting a study of nonconventional materials (particularly advanced composites) and construction to improve the reliability and service life of ocean mooring systems.

Drs. Mark D. Ohman and Victor D. Vacquier, and A. Gail Theilacker, Southwest Fisheries Center, initiated a project to analyze the natural diet of larval fishes. They are developing and calibrating a dietary immunoassay that will permit identification of soft-bodied ciliate protozoa in the guts of larval fish.

Drs. William H. Fenical and D. John Faulkner continued research with a UC Santa Barbara colleague to determine which marine natural products have medicinally useful properties. A number of compounds having significant anti-inflammatory, neuromuscular, and cytotoxic activity already have been described.

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 79,456 nautical miles in fiscal 1989-1990 and operated a total of 757 days. The following charts briefly describe the areas of operations, work performed, and ports of call of this past year's expeditions.

L. D. Ford

Ship personnel prepare vessel for departure.

Research Vessels of Scripps Institution of Oceanography

	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	74.6 m	51.8 m	38.1 m	63.7 m	108.2 m	21.0 m
BEAM	14.0 m	11.0 m	9.8 m	12.0 m	6.0 m	13.7 m
DRAFT	4.9 m	3.7 m	2.8 m	4.4 m	3.4/91.4 m	fwd 1.5m aft 1.6m
DISPLACEMENT FULL (metric tons)	2,108	1,028	532	1,513	1,524	330
CRUISING SPEED (knots)	10	11	9.2	10	varies*	varies*
RANGE (nautical miles)	9,000	7,300	3,300	9,000	varies*	varies*
CREW	23	12	5	23	6	5
SCIENTIFIC PARTY	29-39**	13-26**	12-18**	22	10	10

FISCAL 1989-1990 TOTAL NAUTICAL MILES TRAVELED: 79,456 TOTAL OPERATING DAYS: 757

*Depends on towing vessel **With berthing vans

R/V *Melville*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
7/30-8/5/89	Hydros Leg VIII	Off Miami	Deploy OBS and Deep Tow	Miami	F. Spiess	A. Arsenault
8/8-8/16/89	Hydros Leg IX	Off Miami	Borehole re-entry and equipment deployment	Miami	F. Spiess	R. Haines
9/1-9/10/89	Hydros Leg X	Off Miami	Equipment recovery	Miami	F. Spiess	R. Haines
9/11-9/15/89	Hydros Leg XI	Atlantic	Transit to shipyard	Amelia		R. Haines

TOTAL DISTANCE TRAVELED: 2,420 nautical miles **OPERATING DAYS:** 32

R/V *New Horizon*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
7/1-7/14/89		Northwest of Pt. Conception	Underwater acoustic studies	San Diego	W. Hodgkiss	P. Munsch
7/18-8/8/89	CalCOFI 8907 Legs I, II	California coast	California Current studies	San Diego	M. Mullin	P. Munsch
8/11-8/17/89	Topo 89 Leg I	Fieberling Guyot	Set moorings	San Diego	C. Eriksen (UW)	P. Munsch
8/19-9/3/89	Topo 89 Leg II	Fieberling Guyot	Physical oceanography	San Diego	G. Roden (UW)	P. Munsch
9/8-9/22/89	Topo 89 Leg III	Fieberling Guyot	Biological survey and physical oceanography	San Diego	L. Haury	P. Munsch
9/30-10/15/89	Big "G" Leg I	Fieberling Guyot	Sea floor gravity measurements	San Diego	J. Hildebrand	E. Buck
10/18-11/2/89	Pulse II	Off Pt. Conception	Benthic biology	San Diego	K. Smith	E. Buck
11/6-11/20/89	CalCOFI 8911	Southern Calif. Bight	California Current studies	San Diego	M. Mullin	E. Buck
11/29-11/30/89		Off San Diego and San Diego Trough	RUM III tests and benthic biology	San Diego	G. Wilson	E. Buck
12/11-12/15/89		San Clemente Basin to Patton Escarpment	WOCE CFC inter-comparison exp.	San Diego	R. Weiss	E. Buck
1/6-1/16/90	Topotow	Fieberling Guyot	Geology and Deep Tow	San Diego	P. Lonsdale	E. Buck
1/24-2/8/90	CaBS II Legs I, II, III	Southern Calif. Bight	California basin studies	San Diego (Intermediate port stops in San Pedro)	N. Kachel/F. Azam	E. Buck
2/12-2/27/90	Pulse III	Off Pt. Conception	Benthic boundary layer	San Diego	K. Smith	E. Buck
3/4-3/7/90			Transit	Coos Bay, Oregon		E. Buck
3/8-3/18/90		Gorda Ridge	Multi-tracer studies	Newport, Oregon	R. Collier (OSU)	E. Buck
3/18-3/21/90			Transit	San Diego		E. Buck
3/22-4/19/90		Gulf of California	Benthic biology	San Diego (Intermediate port stops in Mazatlan)	A. Devol (UW)	R. Haines
4/23-5/17/90	Quagmire II	14°42'N, 125°24'W	RUM III investigations	San Diego	G. Wilson	E. Buck
6/18-7/3/90	Pulse IV	Southern Calif. Bight	Benthic boundary layer	San Diego	K. Smith	E. Buck

TOTAL DISTANCE TRAVELED: 22,232 nautical miles **OPERATING DAYS:** 258

R/V *Robert Gordon Sproul*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
7/2-7/8/89		S. Calif. Continental Borderland basins	Collection of benthic organisms	San Diego	S. France	L. Zimm
7/15-8/11/89		Sea of Cortez	Shark navigation	San Diego (Intermediate port stops in La Paz)	P. Klimley (BBL)	L. Zimm
8/12-8/23/89		West of Baja Calif.	Student cruise/ magnetometer studies	San Diego	P. Lonsdale	L. Zimm
9/12-9/14/89		San Clemente Basin	Benthic biology	San Diego	A. Yayanos	L. Zimm
10/7-10/10/89		Off Santa Catalina Island	Water sampling	San Diego	D. Lal	L. Zimm
10/13-10/27/89	Orincon	Off L.J., between Santa Cruz and Santa Rosa Is.	Sea surface studies	San Diego	A. Carlucci	L. Zimm
11/7-11/15/89		Santa Cruz Basin	Tracer studies	San Diego	J. Ledwell (LDGO)	L. Zimm
11/18-11/21/89		Santa Barbara Basin and Santa Monica Bay	Collection of clams	San Diego	J. O'Brien	L. Zimm
12/5-12/7/89		San Clemente Basin	Benthic biology	San Diego	A. Yayanos	L. Zimm
12/20-12/21/89		Off San Diego	Acoustic studies	San Diego	W. Hodgkiss	L. Zimm
2/27-3/1/90		San Clemente Basin	Benthic biology	San Diego	A. Yayanos	L. Zimm
3/12-3/15/90		Santa Barbara Channel	Collection of clams	San Diego	H. Felbeck	L. Zimm
3/27/90		Off San Diego	Equipment testing	San Diego	T. Boegeman	L. Zimm
3/28/90		Off San Diego	Equipment testing	San Diego	T. Boegeman	L. Zimm
3/30/90		Off San Diego	Equipment testing	San Diego	T. Boegeman	L. Zimm
4/6/90		Off San Diego	Equipment testing	San Diego	T. Boegeman	L. Zimm
4/17-4/21/90		Santa Monica Basin	Calif. basin studies	San Diego (Intermediate port stops in San Pedro)	C. Trees	L. Zimm
4/30-5/2/90		San Clemente Basin	Geochemistry	San Diego	C. Reimers	L. Zimm
5/5/90		Off San Diego	Student cruise	San Diego	R. Rosenblatt	L. Zimm
5/9-5/12/90		Southwest of San Diego	Tracer studies	San Diego	D. Lal	L. Zimm
5/21-5/25/90		Santa Cruz Basin	Marine geodesy	San Diego	F. Spiess	L. Zimm
5/30-5/31/90		Off Dana Point	Ocean optics	San Diego	W. Doss (Tetratech)	L. Zimm
6/14/90		Off La Jolla	Equipment testing	San Diego	A. Chave (Bell Labs)	L. Zimm
6/20/90		Off San Diego	Seabird/CTD testing	San Diego	T. Hayward	L. Zimm
6/26-6/28/90		Cortes Bank	ALACE testing	San Diego	R. Davis	L. Zimm

TOTAL DISTANCE TRAVELED: 9,356 nautical miles **OPERATING DAYS:** 114

R/V *Thomas Washington*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
8/17-8/18/89		Off San Diego	Test cruise	San Diego		T. Desjardins
8/28-10/2/89	Venture Leg I	Eastern Equatorial Pacific	Sediment studies: Sea Beam, seismics, and piston coring	Manzanillo	N. Pisias (OSU)	T. Desjardins
10/6-11/7/89	Venture Leg II	East Pacific Rise	Sea Beam and dredging	Manzanillo	J. Bender (UNCC)/ C. Langmuir (LDGO)	A. Arsenault
11/12-12/15/89	Venture Leg III	East Pacific Rise, 9-10°N	Hydrothermal vent studies	San Diego	R. Haymon (UCSB)/ D. Fornari (LDGO)	T. Desjardins
1/5-1/16/90	Plume Leg I	East Pacific Rise, 13°N	OBS deployment	Galapagos	C. Cox	T. Desjardins
1/16-2/21/90	Plume Leg II	Galapagos area	Sea Beam and dredging	San Juan (Intermediate port stops in Galapagos and Rodman)	D. Christie (OSU)	T. Desjardins
2/23-3/5/90	Plume Leg III	Transit		Recife		T. Desjardins
3/8-4/11/90	Plume Leg IV	Middle Atlantic Ridge	Sea Beam and dredging	Montevideo	J. Orcutt/ J. Forsyth (Brown)	A. Arsenault
4/18-5/22/90	Plume Leg V	Middle Atlantic Ridge	Sea Beam and dredging	Recife	P. Fox (URI)/ P. Michael (U.of Tulsa)	T. Desjardins
5/25-6/2/90	Plume Leg VI	Coast of South America	Transit	La Guaira		T. Desjardins
6/5-6/26/90	Plume Leg VII	Cariaco Basin, off Venezuela	Seismics and coring	La Guaira	J. Overpeck (LDGO)/ L. Peterson (RSMAS)	T. Desjardins

TOTAL DISTANCE TRAVELED: 43,542 nautical miles **OPERATING DAYS**: 288

R/P FLIP

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	*OIC
7/29-8/7/89		32°50'N, 120°50'W	SWAPP test cruise	San Diego	R. Weller (WHOI)	*D. Efird
9/13/89		32°50'N, 117°35'W	Equipment testing	San Diego	F. Fisher	*D. Efird
12/4-12/17/89		32°45'N, 120°48'W	SWAPP instrument tests, set moorings	San Diego	R. Pinkel	*D. Efird
2/16-3/22/90		35°8'N, 128°W	SWAPP experiment	San Diego	R. Weller (WHOI)	*D. Efird
5/22-5/26/90		32°50'N, 117°35'W	DIFAR element test	San Diego	W. Hodgkiss	*D. Efird

TOTAL DISTANCE TOWED: 1,906 nautical miles **OPERATING DAYS**: 65 * Officer-in-charge of floating platform

R/P ORB

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

TOTAL DISTANCE TOWED: 0 nautical miles **OPERATING DAYS**: 0 *Officer-in-charge of floating platform

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

Dr. Robert R. Hessler and graduate student Michel A. Boudrias observe an experiment on hydrodynamic drag in a swimming crustacean.

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 1989, 44 new students were admitted to graduate study. Of these, 10 were in marine biology, 3 in geological sciences, 6 in geochemistry and marine chemistry, 9 in geophysics, 8 in physical oceanography, 7 in applied ocean sciences, and 1 in biological oceanography. Enrollment at the beginning of the academic year was 186. UC San Diego awarded 29 Doctor of Philosophy degrees and 14 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

Mark S. Burnett, "The Crustal Structure of the East Pacific Rise Near 12°50'N: Results from the MAGMA Seismic Refraction Experiment."

David W. Caress, "Some Aspects of the Structure and Evolution of Oceanic Spreading Centers."

Qun C. Cheng, "Geochemical Studies of Hotspot Volcanism in the Southern Pacific and Its Implications to Mantle Structure and Dynamics."

Scott W. Jones, "Chaotic Advection of Tracers."

Kristine M. Larson, "Precision, Accuracy, and Tectonics from the Global Positioning System."

Tissa Munasinghe, "Some Aspects of the Tectonic Evolution of the Sri Lanka Continental Margin."

David F. Naar, "Large-Scale Plate Boundary Reorganization at the Easter Microplate."

Anthony E. Schreiner, "Observations of Seafloor Ambient Noise with an Ocean Bottom Seismometer Array."

Laura B. Stokking, "Chemical Remanent Magnetization in Synthetic Hematite."

Robert L. Woodward, "Structure of the Earth's Upper Mantle from Long-Period Seismic Data."

Marine Biology

Stephen C. Cary, "Characterization of Resource Utilization of Marine Invertebrates Harboring Chemoautotrophic Endosymbiotic Bacteria."

Donald A. Croll, "Diving and Energetics of the Thick-Billed Murre: The Cost of Being a Penguin that Flies."

Allen G. Gibbs, "Pressure Adaptation of Na+/K+-Adenosine Triphosphatase in Marine Teleost Gills."

Ngai C. Lai, "Cardiovascular and Respiratory Adjustments to Exercise in the Leopard Shark, *Triakis semifasciata*."

Oceanography

Janet M. Becker, "Three-Dimensional Cross-Waves."

Timothy J. Boyd, "Upper Ocean Internal Waves in the Central Equatorial Pacific."

Julio Candela, "Tidal and Subinertial Flows Through the Strait of Gibraltar."

Daniel R. Cayan, "Variability of Latent and Sensible Heat Fluxes Over the Northern Oceans."

Diane M. Henderson, "Faraday Waves."

Raleigh R. Hood, "Phytoplankton Biomass, Photosynthetic Light Response, and Physical Structure in a Northern California Upwelling System."

Sam F. Iacobellis II, "Diagnostic Modeling of the Indian Summer Monsoon."

Justin Lancaster, "Carbon-13 Fractionation in Carbon Dioxide Emitting Diurnally from Soils and Vegetation at Ten Sites on the North American Continent."

Niels L. Lindquist, "Secondary Metabolite Production and Chemical Adaptations in the Class Ascidiacea."

Marie C. McIntyre, "Design and Testing of a Seafloor Geodetic System."

Cynthia A. Paden, "Tidal and Atmospheric Forcing of the Upper Ocean in the Gulf of California."

Pierre-Marie Poulain, "Surface Circulation Phenomena Off Baja California As Deduced from Satellite-Tracked Drifters."

Jongheon Shin, "Marine Natural Products: Chemistry and Chemosystematics of the Gorgonian Genus *Eunicea* and Exploratory Studies of the Secondary Metabolites from Marine Fungi."

Jean-Marie Q. D. Tran, "Approaches to the Processing of Data from Large Aperture Acoustic Vertical Line Arrays."

Garr E. Updegraff, "In Situ Investigation of Sea Surface Noise from a Depth of One Meter."

Master of Science Degrees

Earth Sciences

Julie J. Dieu

Marine Biology

Steve B. Butler
Lakshmi Chilukuri
Caroline A. L. Gennser
Josephine D. Pino
Michelle D. Pontius-Brewer
John Ricci

Oceanography

Patrick J. Hamilton
Kevin G. Harrison
Eduardo W. Helbling
Akihiko Hirayama
Anne Petrenko
Leslie A. Vakassian
Dong-Xiao Yu

Shore Facilities

SeaMARC II (University of Hawaii) is loaded aboard R/V *Thomas Washington* before a research cruise.

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 Shipboard Technical Support unit is featured throughout this section.

Analytical Facility

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

R/V *Thomas Washington* being loaded for a cruise to the East Pacific Rise.

Perry J. S. Crampton repairs an SSI water gun.

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 Experimental Aquarium (250 m^2) is equipped with 5 rooms for controlled experiments, 20 tanks with capacities from 425 to 2,200 liters, 9 seawater trays, counter space, sinks, and lockers. A single-line 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 experimental animal colony; equipment for measuring circulatory and cardiac functions in conscious, unrestrained animals; and an instrumentation development laboratory.

Diving Facility

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

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

Electromechanical Cable Test Facility

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

Ellen Browning Scripps Memorial Pier

The 320-m pier serves as a launching site for small boats used for local oceanographic work, provides space for nearshore studies and tide gage 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 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,0201 Scripps Institution of Oceanography, 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.

Frank M. Delahoyde checks a CTD before a cruise.

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 governmental and university

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

Scripps Coastal Reserve

The reserve 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 the largest marine science library in the world. The library currently receives more than 3,700 serial titles and has more than 210,000 volumes, including an extensive collection of technical reports and translations, 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.

Seth A. Mogk ties down an instrument aboard ship prior to departure.

Scripps Satellite Oceanography Facility (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.

A new user's center was opened and a user analysis work station is available for general image processing. This system consists of a dedicated HP 9000/370 work station with 16 megabytes of RAM and 1 gigabyte of magnetic disc. The 660 megabyte 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 digital image analysis application. A separate terminal room is available for software development by center users.

A new HP 9000/375 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 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

SeaMARC II being loaded aboard R/V *Thomas Washington.*

network by non-local users.

Current applications include near-real-time support of research vessels and aircraft by using remote detection to determine sea-surface temperature, retrospective analysis of image data sets in relation to physical and biological oceanography studies, and in real-time support of fishing fleet operations. 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.

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, 18-cm-diameter, high-speed sand filters and pumped up into two concrete storage tanks with a total capacity of approximately 450,000 liters. Water flows by gravity to the public aquarium and Scripps research laboratories, while approximately 750 liters per minute are pumped up to the National Marine Fisheries building. The system is capable of delivering a maximum of 7,200 liters per minute.

Shipboard Technical Support

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

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

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

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

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)

Ronald L. Comer and a University of Hawaii employee prepare equipment to be loaded aboard ship.

have participated in many recent multi-institutional expeditions.

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

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

SSURF: SIO Supercomputer Users Remote Facility

The SSURF computer center provides computer services for the Scripps community. A high-speed data connection to the San Diego Supercomputer Center is just one part of SSURF's function. Electronic mail can be sent on ARPAnet, BITnet, NSFnet, OMNet, and SPAN to other computers worldwide. SSURF also has data processing utilities including numerous statistical and plotting software packages, and many different computer programing languages. Consultants provide assistance on software, hardware, electronic mail, intercomputer data transfer, networking, and super-computer 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 gigabytes of disk storage. The SSURF computer center services are available 24 hours a day year-round.

Thomas Wayland Vaughan Aquarium-Museum

The aquarium-museum is the interpretive center for Scripps Institution of Oceanography. Its goals are to increase public understanding and appreciation of the oceans and to generate 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 the Stephen Birch Aquarium-Museum in honor of the major donor, has been designed and is scheduled for completion in 1992. The new facility will be 3 times larger than the present one. The project is expected to cost approximately $9 million, exclusive of parking and roads.

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 36,000 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 percent 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 onshore 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 continuous 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. 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 161 primary types. Approximately 200 collections are added each year. Although the collection is worldwide, deep-sea 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 459 species.

Oceanographic Data Archives

Tide-gage records have been taken daily from the Scripps Pier since 1925. Monthly tide-gage 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, C-233, NOAA/NOS, 6011 Executive Blvd., Rockville, MD 20852.

Data from more than 20,000 hydrographic casts from Scripps cruises are managed by Shipboard Technical Support. 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.

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 complete listing of Scripps publications for 1990 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, 2223 Fulton Street, Berkeley, California 94720.**
The most recent volumes are listed below.

v.26 **Matsui**, Tetsuo and Richard H. **Rosenblatt**. Review of the Deep-Sea Fish Family Platytroctidae (Pisces: Salmoniformes). 1987. 159p.

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

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 41-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 1989 volume and may also be found in the publications cited. Information about a specific reprint can be obtained by writing directly to the author in care of the **University of California, San Diego, Scripps Institution of Oceanography, 9500 Gilman Drive, La Jolla, California 92093.**

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APPENDIX

B

ACADEMIC STAFF

July 1, 1989 - June 30, 1990

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

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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

Dr. George E. Backus Elected a foreign member of the Académie des Sciences in France.

Dr. Jonathan Berger Elected a Fellow of the American Geophysical Union.

Dr. Lanna Cheng Received award for outstanding contributions from the Academia Sinica.

Dr. Richard W. Eppley Elected a Fellow of the American Geophysical Union.

Dr. Edward A. Frieman Elected to the American Philosophical Society. Appointed to the United States Secretary of Energy Advisory Board.

Dr. John R. Hunter Received the Roger Revelle Perpetual Award from the San Diego Oceans Foundation.

Dr. Douglas L. Inman Received an Ocean Science Educator Award from the Office of Naval Research.

Dr. Charles D. Keeling Elected a Fellow of the American Association for the Advancement of Science.

Dr. Ralph A. Lewin Received award for outstanding contributions from the Academia Sinica.

Dr. Lucy-Ann McFadden Elected Secretary of the Planetology Section of the American Geophysical Union.

Dr. John A. McGowan Elected a Fellow of the American Association for the Advancement of Science.

Dr. Eric L. Mills from Dalhousie University. Received the first William E. and Mary B. Ritter Memorial Fellowship from Scripps Institution of Oceanography.

Dr. Jean-Bernard H. Minster Elected a Fellow of the American Geophysical Union.

Dr. Walter H. Munk Awarded the 1989 Bowie Medal by the American Geophysical Union.

Dr. Kenneth L. Smith Elected a Fellow of the American Association for the Advancement of Science.

Dr. William R. Young Received the 1989 Macelwane Medal from the American Geophysical Union.

A P P E N D I X

D

CURRENT FUNDS

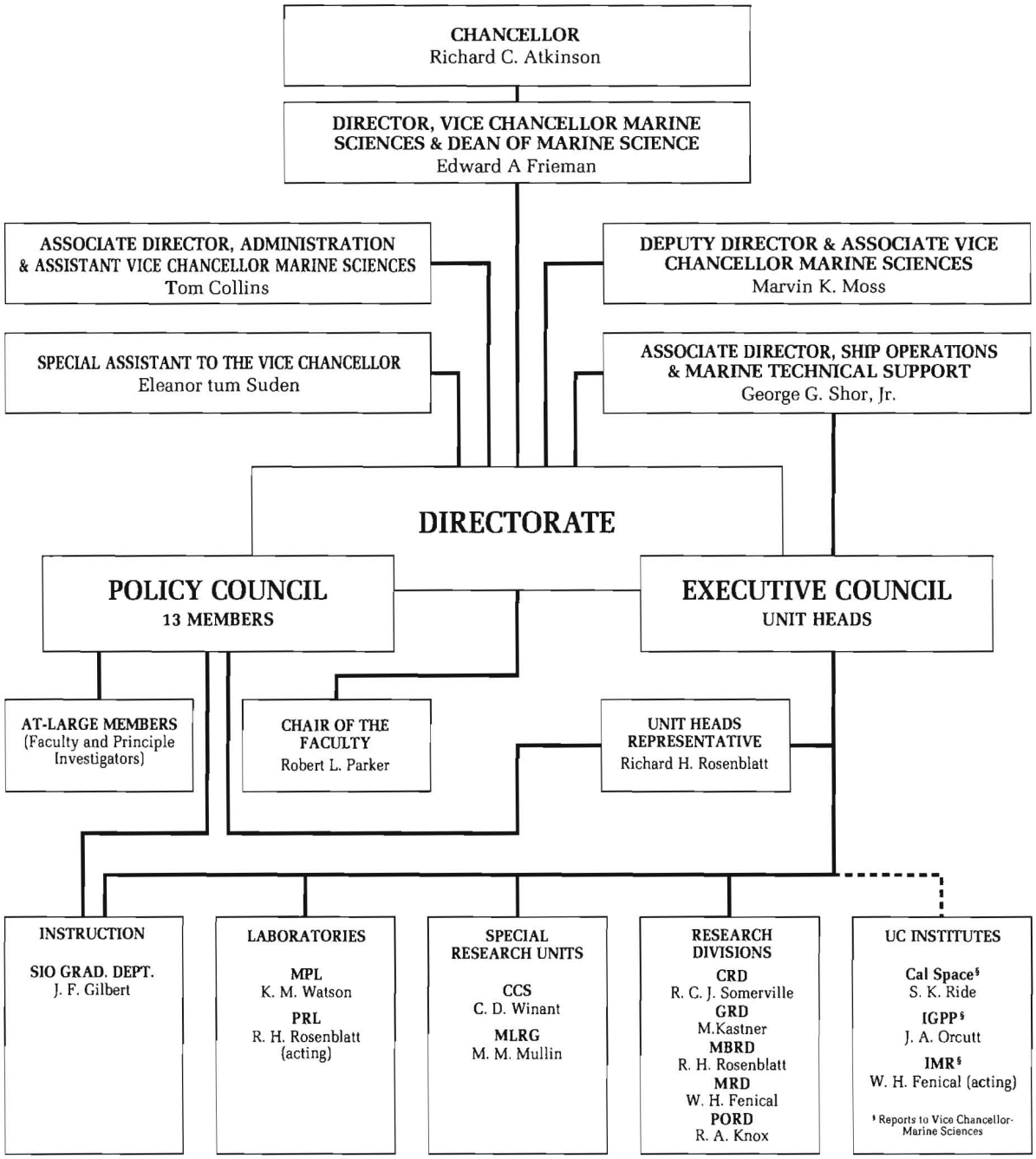
Agency	Expenditures*	Percentage of Total
Federal Government		
National Science Foundation	18,953,396	26.51
Navy, Department of the	15,205,029	21.27
Commerce, Department of	1,984,501	2.78
National Aeronautics and Space Administration	1,796,123	2.51
Health and Human Services, Department of	1,124,415	1.57
Energy, Department of	546,716	0.76
Army, Department of the	2,124,603	2.97
Interior, Department of the	595,459	0.83
Air Force, Department of the	1,313,622	1.84
Other	257,103	0.36
Total Federal Government	**$43,900,967**	**61.40**
State General Funds	15,864,563	22.19
Private Gifts and Grants	7,496,239	10.48
Overhead Funds	1,863,632	2.61
State of California	558,119	0.78
Endowment Funds	172,686	0.24
Local Government	24,086	0.03
Sales and Services	1,623,215	2.27
Total Current Funds Expenditures	**$71,503,507**	**100.00**

*Includes overhead

APPENDIX

E

ORGANIZATION*



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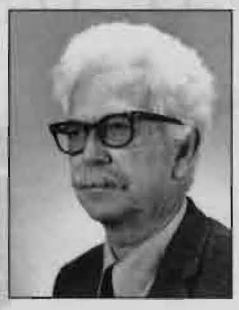
IN MEMORIAM

Brian P. Boden. October 6, 1989. Brian Boden was a biologist in the Marine Biology Research Division from 1955 until his retirement in 1967. He studied the deep scattering layer and bioluminescence.

William T. Coulbourn. June 13, 1990. Bill Coulbourn was a geologist in the Geological Research Division from 1977 until 1984. He had also been part of the Deep-Sea Drilling Program.

Richard H. Fleming. October 25, 1989. Dr. Fleming, an early leader in the development of U. S. oceanography, served the Scripps faculty from 1935 through 1941. He co-authored *The Oceans, Their Physics, Chemistry and Biology*, the first modern textbook in oceanography.



Theodore R. Folsom

Theodore R. Folsom. October 6, 1989. Dr. Folsom was a research oceanographer from 1952 through 1975. He pioneered the development of methods for tracking radioactive contaminants in the ocean. One of the founders of Mount Soledad Laboratory, Dr. Folsom directed the facility for 25 years and was returned to active duty until 1984.

Robherd E. Lange. April 14, 1990. Dr. Lange earned his Ph.D. degree from Scripps in 1974. He worked at Scripps on oceanic microstructure and planktonic biology. Later he studied the theoretical aspects of advanced Dopplar sonar.

Frank Miller. January 30, 1990. Captain Miller joined the Scripps fleet in 1949 as a seaman, became an officer, and retired as a Senior Captain in 1967. He was involved with many expeditions including Scripps's Naga Expedition and Operation Wigwam.

Harold Sammuli. September 20, 1989. Harold Sammuli worked for Scripps from 1958 through 1969. He first served as shipboard radio operator and later as the operator/modifier of Scripps's "Archer" seismic reflection system.

H. George Snyder

H. George Snyder. April 13, 1990. George Snyder, Museum Scientist, joined Scripps Marine Life Research Group in 1955. He maintained the renowned plankton collection until his death.

Beatrice M. Sweeney. July 19, 1989. Beatrice Sweeney was on the Scripps Marine Biology research staff from 1947 through 1961. She was among the first to isolate marine dinoflagellates into culture and to demonstrate a vitamin requirement for growth.

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