SCRIPPS INSTITUTION OF OCEANOGRAPHY 1981

University of California, San Diego

Cover: Adult *Euphausia superba* (also known as krill), major source of food for Antarctic whales, seals, and penguins.

COVER BY L. D. FORD

DEDICATION

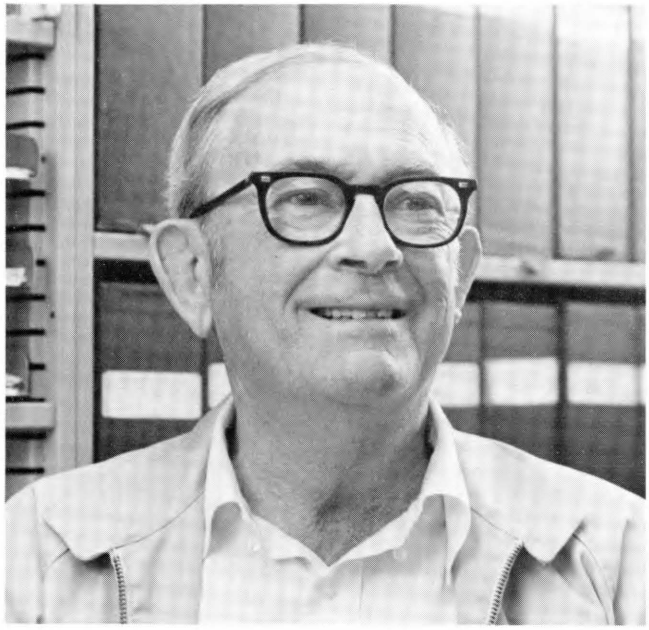
The search for small creatures has taken him onto the deep sea and alongside desert lagoons. While spanning continents he has also spanned disciplines.

Dr. Fred B Phleger is a geologist, but his specialty is foraminifera—minute protozoans with devastatingly long names and an importance that belies their size. Their significance lies in their calcareous shells which, properly interpreted, become index fossils for dating sediments and interpreting environments. Dr. Phleger is an authority on the ecology of foraminifera, and on the relationship between their distribution and changes in ocean temperature and circulation.

From Amherst College and Woods Hole Oceanographic Institution Dr. Phleger came to Scripps as a visiting associate professor in 1949, and was permanently appointed in 1951. He had aleady been to sea on the *Albatross* of the 1947 Swedish Deep Sea Expedition, to collect long sediment cores. At Scripps he directed the Marine Foraminifera Laboratory for some years, and was instrumental in obtaining a large grant from the American Petroleum Institute (API 51) to study the Recent sediments of the northwestern Gulf of Mexico; the project was directed by Dr. Francis P. Shepard.

WOODS HOLE OCEANOGRAPHIC INSTITUTION

In pursuit of foraminifera, Dr. Fred B Phleger uses a Clarke-Bumpus plankton net in the Gulf of Mexico on Atlantis *in 1947.*



Dr. Fred B Phleger

Coastal marshes, deltas, and lagoons caught Dr. Phleger's interest on the East Coast, and at Scripps he continued to investigate them in detail. His most dramatic researches have been of the coastal lagoons of Baja California, with the help of his flying colleague, Dr. Gifford C. Ewing. Dr. Phleger went on to reconnoiter all the lagoons of the Mexican coast. His cooperation and interest in Mexican scientific researches led to his being honored in 1981 as "Profesor Extraordinario" of the Universidad Nacional Autónoma de México.

Emeritus Professor Phleger has contributed a considerable output of scientific publications, but his greatest writing challenge, he says, was five books in two popular beginning reader series for children.

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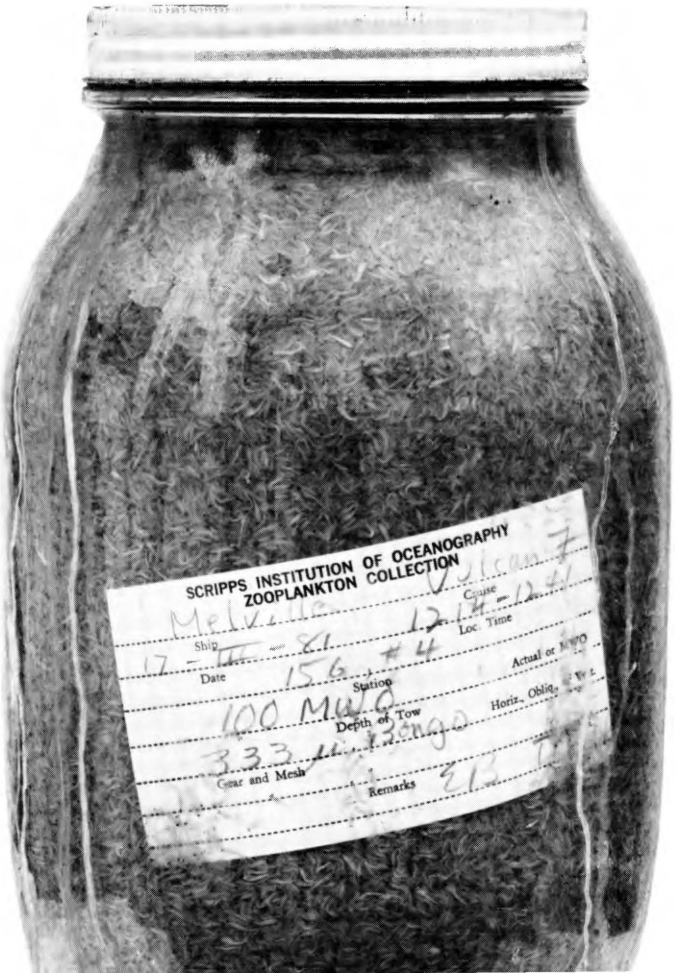
UNIVERSITY OF CALIFORNIA SAN DIEGO



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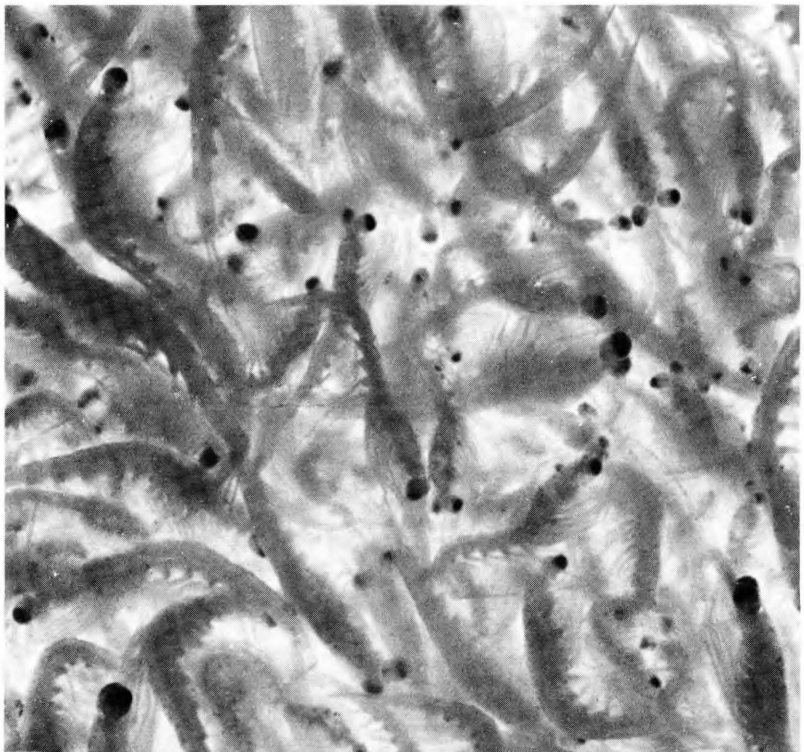


INTRODUCTION

These have been very exciting and fruitful years in times of expanding scientific technology. The expansion has been so rapid that now is a good time to assess the progress and learn for the future. The satellite-oceanography facility is fully operational—it is essentially performing a three-shift day, seven-day week. It is unique at this time as an oceanographic facility and is carrying out a wide spectrum of functions. In fact it is already at the point where the computing system must be modernized. We were not adequately prepared for success.

The multibeam seismic development of the last five years has taken a curious turn. Digitizing the signal to accommodate multibeam processing is yielding a processed, single-channel signal of a quality more than adequate for most geophysical applications. This results in considerable dollar savings. However, before we congratulate ourselves, we must remember that digital signal processing and beam forming was first developed at SIO—MPL to be exact—by Victor Anderson about twenty years ago. That is too long for an internal technology transfer!

This is not the first time this has occurred. The Fast Fourier Transform was developed and used at SIO-MPL by Phil Rudnick even earlier, but it had to be reintroduced elsewhere in the institution from the outside, where it was rediscovered years later.

At the present time our biggest technical investment is the installation of Sea Beam equipment on R/V *Thomas Washington*. This will be the first U.S. civilian research vessel to be so equipped and will be the only one for a number of years. The equipment will allow the production of underway, on-line bathymetric charts in the deep ocean covering a wide swath of the bottom. It should be operational by the end of 1981 and should produce useful results before this time next year. It is cooperatively supported by ONR and SIO/Fleishmann Foundation funds.

Leaving hardware, we note the establishment of the Experimental Climate Forecast Center—a joint effort of NOAA and SIO. The center makes a group of three independent forecasts each quarter. Two quarters have now gone by with interesting results.

Another important initiation this year was the Andrew W. Mellon Fellowship Program. This program will support four or five fellows a year in a variety of fields. There are adequate funds on hand for a five-year program.

If I were to anticipate—as I should—where the next intellectual ferment will develop, I would guess that it would be biological oceanography. There are several indicators. For the first time what would seem to be a critical number of capable researchers is apparently available. Secondly, a variety of new technologies such as satellite-oceanography has been developed. Finally the body of related nonlinear mathematics is developing very rapidly and is a powerful theoretical tool for supporting the subject.

One light note—R/V *Ellen B. Scripps* has paid off her mortgage this year—five years early. She has served us well and will continue for many more years. One could wish that computers could last as long. It is true that our seagoing 1800s have been around as long as *Ellen B. Scripps,* but the real lifetime of modern computers seems to be from three to five years, and what new system to acquire is a most agonizing question.

However, these are all positive problems. Their solutions mean better and more important research. Despite the extraordinary changes emanating from Washington it is clear that we will be busy for a long time to come.

William A. Nierenberg

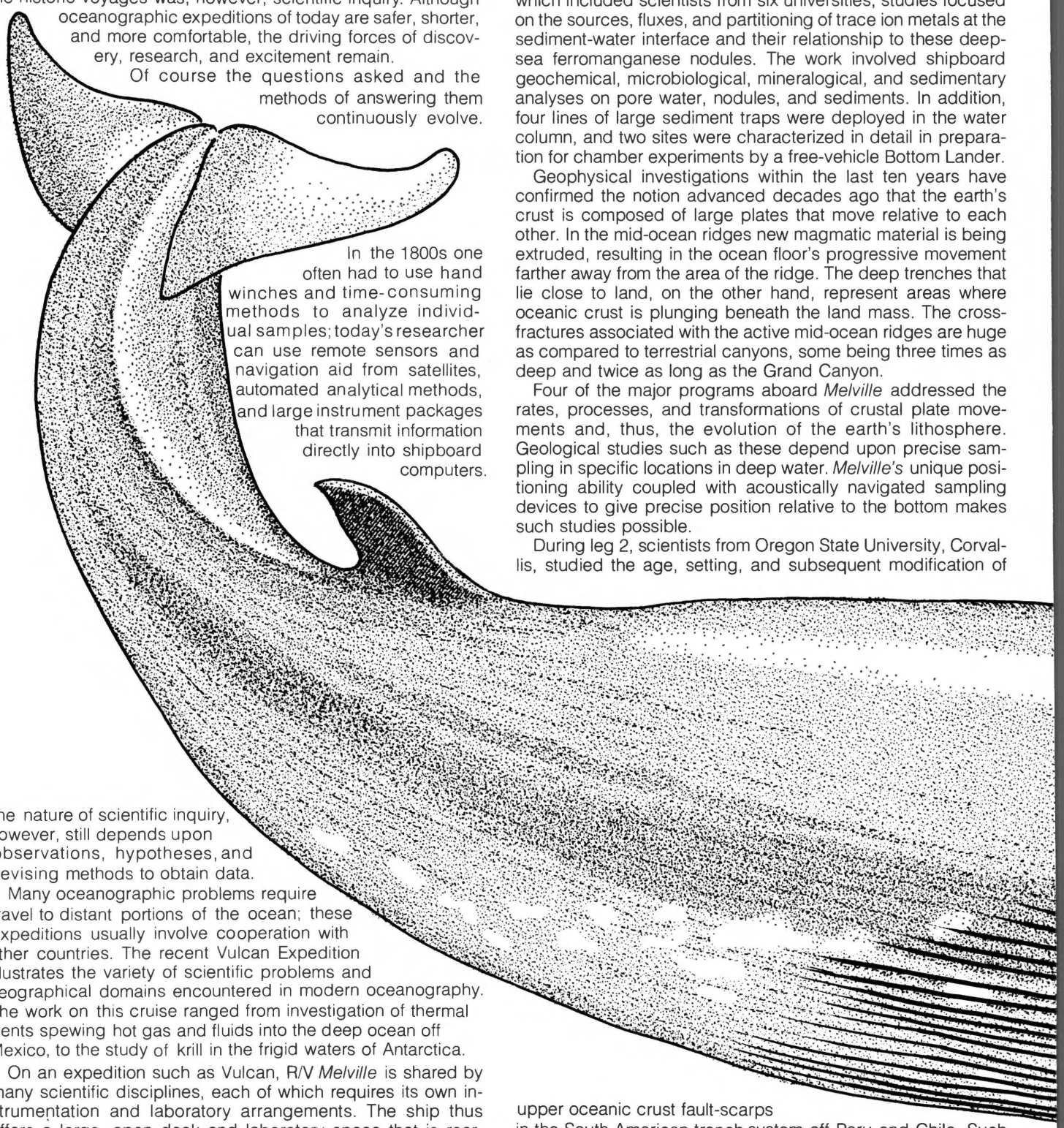
William A. Nierenberg, Director
Scripps Institution of Oceanography

VULCAN EXPEDITION

***Study nature, not books.* Alexander Agassiz.** Famous voyages of the past, such as charles Darwin's or Fridtjof Nansen's, evoke thoughts of geographical exploration, excitement, hardships, and danger. The motivating force behind most of the historic voyages was, however, scientific inquiry. Although oceanographic expeditions of today are safer, shorter, and more comfortable, the driving forces of discovery, research, and excitement remain.

Of course the questions asked and the methods of answering them continuously evolve.

In the 1800s one often had to use hand winches and time-consuming methods to analyze individual samples; today's researcher can use remote sensors and navigation aid from satellites, automated analytical methods, and large instrument packages that transmit information directly into shipboard computers.



The nature of scientific inquiry, however, still depends upon observations, hypotheses, and devising methods to obtain data.

Many oceanographic problems require travel to distant portions of the ocean; these expeditions usually involve cooperation with other countries. The recent Vulcan Expedition illustrates the variety of scientific problems and geographical domains encountered in modern oceanography. The work on this cruise ranged from investigation of thermal vents spewing hot gas and fluids into the deep ocean off Mexico, to the study of krill in the frigid waters of Antarctica.

On an expedition such as Vulcan, R/V *Melville* is shared by many scientific disciplines, each of which requires its own instrumentation and laboratory arrangements. The ship thus offers a large, open deck and laboratory space that is reorganized by each group of investigators when they join the ship. Scientists aboard the Vulcan Expedition carried out studies in geology, geophysics, physical and chemical oceanography, and biology.

One of the more interesting scientific discoveries in recent years was the great abundance of manganese nodules over large areas of the ocean floor. Not only do these nodules present challenging questions regarding their origin, but they also represent a potentially valuable source of cobalt and nickel as well as manganese. During leg 1 of the Vulcan Expedition, which included scientists from six universities, studies focused on the sources, fluxes, and partitioning of trace ion metals at the sediment-water interface and their relationship to these deep-sea ferromanganese nodules. The work involved shipboard geochemical, microbiological, mineralogical, and sedimentary analyses on pore water, nodules, and sediments. In addition, four lines of large sediment traps were deployed in the water column, and two sites were characterized in detail in preparation for chamber experiments by a free-vehicle Bottom Lander.

Geophysical investigations within the last ten years have confirmed the notion advanced decades ago that the earth's crust is composed of large plates that move relative to each other. In the mid-ocean ridges new magmatic material is being extruded, resulting in the ocean floor's progressive movement farther away from the area of the ridge. The deep trenches that lie close to land, on the other hand, represent areas where oceanic crust is plunging beneath the land mass. The cross-fractures associated with the active mid-ocean ridges are huge as compared to terrestrial canyons, some being three times as deep and twice as long as the Grand Canyon.

Four of the major programs aboard *Melville* addressed the rates, processes, and transformations of crustal plate movements and, thus, the evolution of the earth's lithosphere. Geological studies such as these depend upon precise sampling in specific locations in deep water. *Melville's* unique positioning ability coupled with acoustically navigated sampling devices to give precise position relative to the bottom makes such studies possible.

During leg 2, scientists from Oregon State University, Corvallis, studied the age, setting, and subsequent modification of upper oceanic crust fault-scarps in the South American trench system off Peru and Chile. Such exposed clefts in the earth's crust are unique tectonic features in the ocean basins and enable geologists to study transform-

ations of rock that are ordinarily deep below the ocean floor. The data will be used to evaluate the compositional variability of glassy basalts associated with fault scarps so that they can describe both the scale of mantle source rock heterogeneities and the processes responsible for evolution of magmas generated beneath a fast-spreading center. The data will also be used to examine the recent development of oxidative, low-temperature seawater effects on oceanic crust initially altered or metamorphosed under much different conditions.

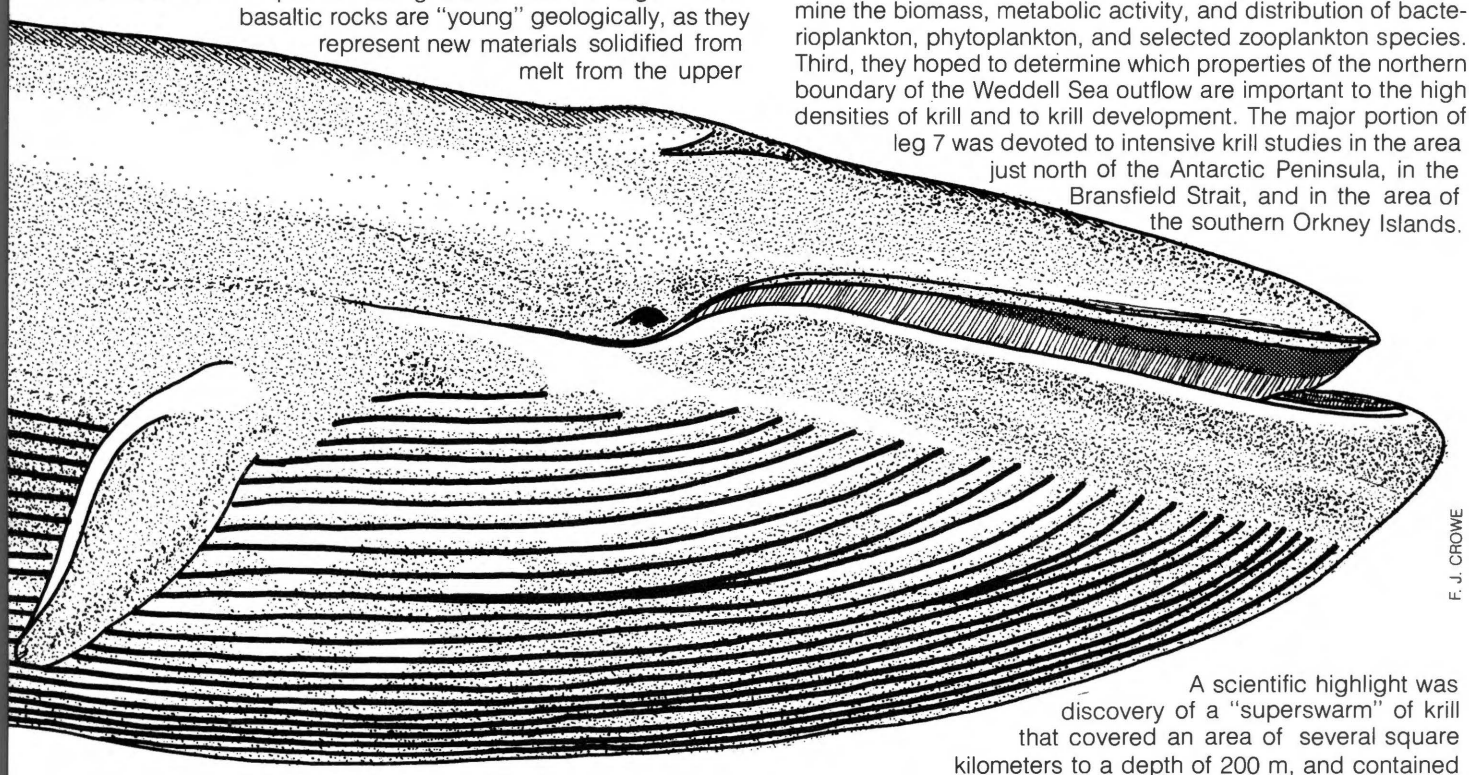
Another consequence of the convergence of an oceanic crustal plate with the South American continent, which has created the 5000-km-long Peru-Chile Trench, is that the sedimentary layers of rock overlying the igneous basement rock are dramatically contorted and transformed. A study of the sedimentary facies and stratigraphy of the trench allows an interpretation of its age and formative processes. The Chilean continental margin is a key area for the study of such trench stratigraphy because the climatic regions along this narrow country vary rather systematically from the extremely arid Atacama Desert in the north to the heavily glaciated, fjord-cut islands in the south. As a result, there is a nearly complete spectrum of precipitation, denudation, and resulting sedimentation rates in the adjacent trench basin. Fast plate convergence rates (10 cm/year) explain the influence of tectonism on the evolving trench stratigraphy, and apparently can produce abrupt changes in trench wedge facies. Seismic reflection data and piston core samples obtained during Vulcan Legs 3 and 4 will be used to interpret the evolution of the sedimentary facies.

During leg 5, scientists from Woods Hole Oceanographic Institution and Massachusetts Institute of Technology studied the petrologic variations along the mid-ocean spreading ridge. Continuous underway data collection included magnetics, seismic profiling, gravity, and depth profiling. Dredges were used to obtain basaltic rocks from the seismically active ridge crest between the Bouvet triple junction and the western termination of the ridge at the South Sandwich transform fault. These rocks will be studied for systematic chemical changes associated with their position along and across the ridge. These basaltic rocks are "young" geologically, as they represent new materials solidified from melt from the upper mantle or from magma chambers in the lower crust that have been extruded into crustal areas of the ocean ridges.

The January change of scientific personnel on *Melville* in Punta Arenas signaled a shift in the research program to a multidisciplinary study of the Scotia and Weddell seas. One focal point for the next two legs was the distribution, abundance, and life cycle of the shrimplike crustacean *Euphausia superba*. These organisms, known as krill (a Norwegian word meaning "food for whales") reach a length of 5 cm and an age of 4 years and are the major source of food for Antarctic whales, seals, penguins, and many fish. Krill feed directly upon phytoplankton (unicellular, photosynthetic algae) that form the base of the food chain in Antarctic waters and are enormously concentrated there. Although Antarctic waters represent only about 15 percent of the world's ocean area, fisheries experts estimate that between 100 and 200 million metric tons of krill can be harvested each year for human consumption. This compares with a total fish catch at present of about 70 million metric tons for all the oceans.

There is still a great deal to be learned about the life cycle of krill in the Antarctic and about the dynamics of the food chain that can sustain such an enormous production of krill, seals, and whales. One of the baffling problems is that the phytoplankton's rate of primary production is fairly low (only about one-half or less the rate of phytoplankton photosynthesis in southern California waters), and yet the higher trophic levels (krill and whales, etc.) are in greater abundance than off California. To unravel this mystery requires studies of the physical and chemical milieu in Antarctic waters relative to the biological components, as well as specialized studies on the physiology, biochemistry, and nutrition of phytoplankton and zooplankton. During legs 6 and 7 *Melville* was part of an international program with 17 ships from 12 countries; the ships covered the major krill areas in the Southern Ocean.

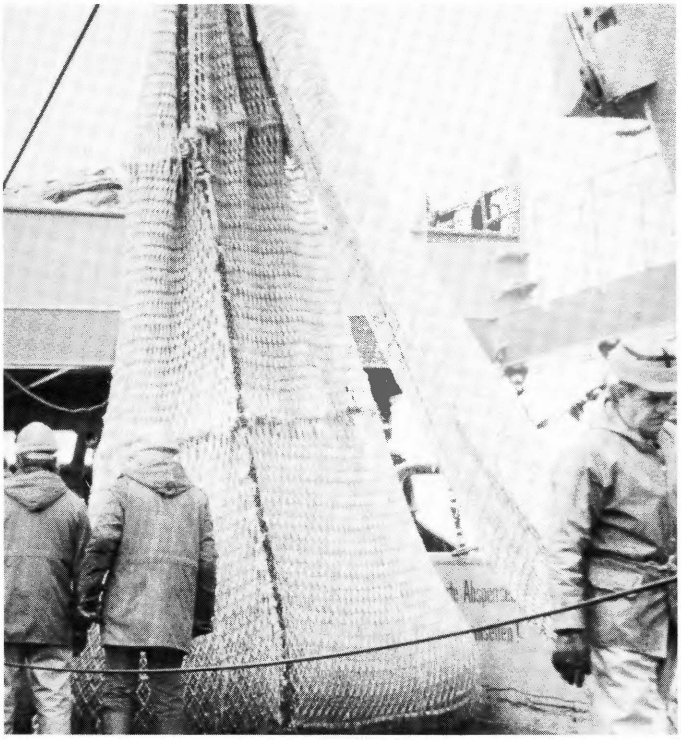
Scientists aboard *Melville* studied the confluence of Drake Passage waters and the northern outflow of the Weddell Sea, with three specific objectives. First they investigated the relationship between the physical and biological characteristics of confluent water masses. The second objective was to determine the biomass, metabolic activity, and distribution of bacterioplankton, phytoplankton, and selected zooplankton species. Third, they hoped to determine which properties of the northern boundary of the Weddell Sea outflow are important to the high densities of krill and to krill development. The major portion of leg 7 was devoted to intensive krill studies in the area just north of the Antarctic Peninsula, in the Bransfield Strait, and in the area of the southern Orkney Islands.



F. J. CROWE

A scientific highlight was discovery of a "superswarm" of krill that covered an area of several square kilometers to a depth of 200 m, and contained approximately 10 million metric tons of krill.

Blue whale (Sibbaldus musculus)



P. R. STEVENS

Scientists and workers look at a net filled with krill aboard the West German research vessel Walther Herwig *in the Antarctic.*

A remnant of history was also visited during this cruise when *Melville* dropped anchor for a few hours in Yankee Harbor, Deception Island, which was the site of one of the first whaling stations in the Antarctic in the nineteenth century. After spending 63 days amid the icebergs and frozen landscapes, *Melville* rounded Cape Horn on a calm, sunny day, and returned to Punta Arenas, Chile, via the Beagle Channel, where all enjoyed watching the soaring Andean condors amid the conifer-covered mountains.

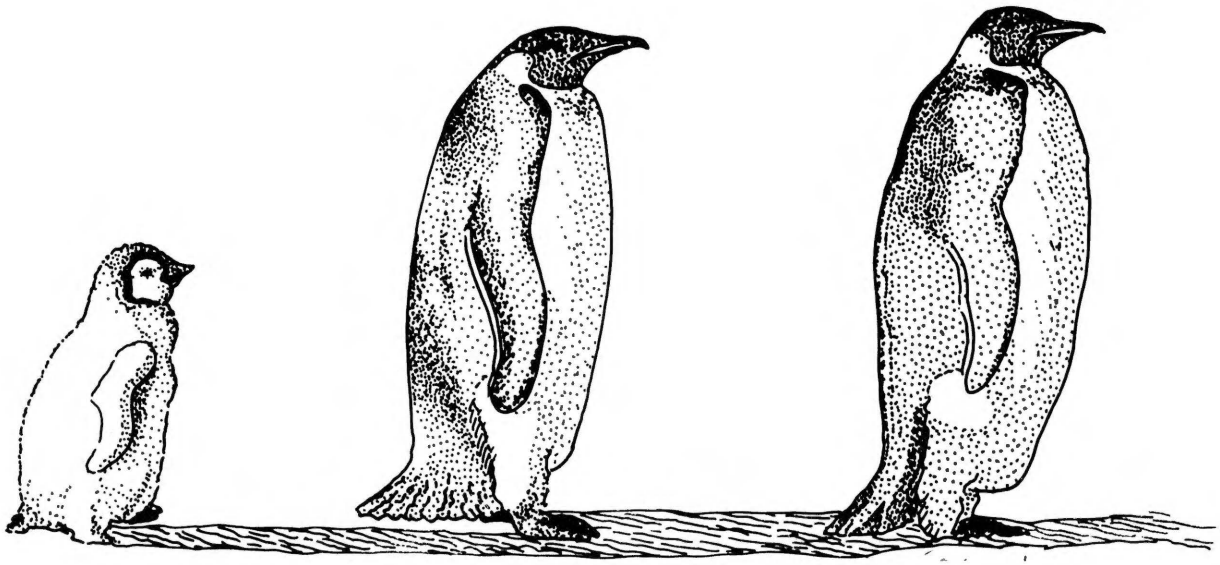
Another aspect of tectonic movements of the ocean floor was investigated during Vulcan Legs 8 and 9. The primary objective was the search for new hydrothermal vent fields on the East Pacific Rise at latitude 10-20°S. This section of the rise is the fastest-spreading oceanic sea floor in the world. The plates are separating at a rate of about 20 cm a year, and deep-mantle lava is rising between the plates to create new oceanic crust, bringing with it a large flux of gases and volatiles from the earth's interior. The major techniques used to detect these hydrothermal vents were to examine water samples for helium and methane, two volatile gases injected into the oceans from the deeper-lying magma, and to deploy an acoustically navigated camera system, which is towed 10 m above the bottom, snapping color photographs every 30 seconds.

Two new fields of hydrothermal vents were located. Photographs show large communities of animals similar to those observed at 21°N. The creatures include giant clams, mussels, anemones, starfish, large whelks, two kinds of crabs, and several types of fish, all adapted to a food chain based on bacterial use of hydrogen sulfide, another volatile emitted in the vent areas. Of most interest are great numbers of large grey worms, tentatively identified as Hemichordates (acorn worms), members of a phylum intermediate between vertebrates and invertebrates. Such acorn worms are distributed widely on the world's ocean floors, but here their abundance is remarkable.

Geological structures observed at the vent areas included sulfide chimneys, the edifices from which the hot, turbid waters emerge, and fresh pillow flow and sheet flow lavas. The sulfide deposits, which contain compounds of copper, silver, and other metals, are similar to those observed at 21°N, but are expected to be much more extensive. Dredging for basalt samples was also done along the ridge crest, from ~20°S to the equator. The samples will be used for various shore-based studies, including petrology, trace elements, rare earth isotopes, U and Th isotopes, ^{3}He, and rare gases.

In major expeditions like Vulcan, ships continuously log underway data including bathymetry and magnetics, which go into data banks where they are available to anyone.

Melville returned to San Diego on May 27, 1981, having completed another voyage of discovery.



F. J. CROWE

CLIMATE RESEARCH GROUP

Why study climate at an oceanographic institution? Because the climate is profoundly affected by the ocean.

One remarkable property of the atmosphere is that it has a very short "memory." Atmospheric conditions change rapidly in contrast to ocean circulation, and this time-scale mismatch helps to define climate in a natural way.

Weather systems have brief lives: cloud-scale motions last only a few hours, and even the largest storms disappear in a week or two. Weather forecasting—observing the turbulent atmosphere and attempting to predict its evolution in detail—is limited to these time spans. Beyond a few weeks, weather merges into climate, a vast subject encompassing every influence on the global atmosphere and the earth's surface.

The Climate Research Group, under the direction of Dr. Richard C. J. Somerville, studies climate variability, emphasizing time scales ranging from several weeks to several years. During these periods, weather fluctuates unpredictably and contributes a large random component to climate variation. Simultaneously, the atmosphere interacts strongly with the underlying land, ice, and ocean. Heat, water, and momentum are constantly exchanged across the air-sea boundary. In comparison to the atmosphere, the ocean moves slowly and has a large heat capacity. Only by considering the atmosphere and the ocean as a coupled fluid system can the long-term climate variability be understood.

What are the prospects for successful climate prediction? Several techniques show promise in seasonal forecasts for temperature and precipitation over the United States. No method has yet proved consistently superior, and the reliability of existing methods leaves much to be desired: even the best ones occasionally produce dramatically wrong forecasts.

Uniformly skillful seasonal forecasts, valid for all regions of the world and all times of the year, will probably never be possible. Climate may simply be more predictable in some areas than in others. For example, the climate in the coastal regions of the United States is generally much more predictable than in the interior of the country, according to a recent study by Dr. Tim Barnett. Similarly, complex phenomena such as El Niño, which involves the anomalous invasion of warm water into the eastern equatorial Pacific, appear to have predictable aspects.

Drs. Geoffrey K. Vallis, John O. Roads, and Richard C. J. Somerville interpret their computer simulation of atmospheric circulation.

Methods used today for short-term weather forecasting—dynamical models founded on basic physical laws—may become essential to long-range predictions. At present, however, scientists using the most complicated climate models—which require the speed of the largest computers—cannot reliably forecast seasonal anomalies. The failings of these models stem from a lack of physical understanding and especially from unsatisfactory techniques for modeling the coupled ocean-atmosphere system.

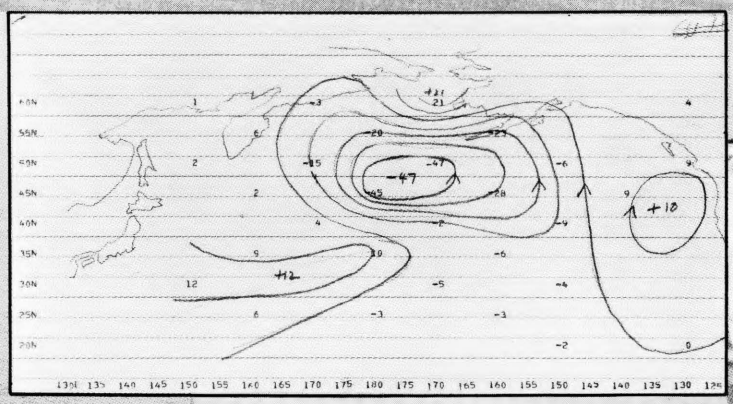
Current atmospheric models are seriously inadequate for simulating the behavior of planetary waves—the continent-sized features that set the stage for cyclone-scale drama of daily weather. Drs. John O. Roads, Somerville, and Geoffrey K. Vallis have constructed idealized models of planetary waves and studied their sensitivity to modeling assumptions. In nature, such waves are influenced by smaller-scale waves, by mountain ranges, by thermal and frictional contrasts between oceans and continents, and by ocean surface temperature anomalies. These processes and the improvement of their representation in models are being explored by Drs. Roads, Somerville, and Vallis. A goal of complementary research by Dr. Barnett is the combination of dynamics and statistics in models of climatic variation.

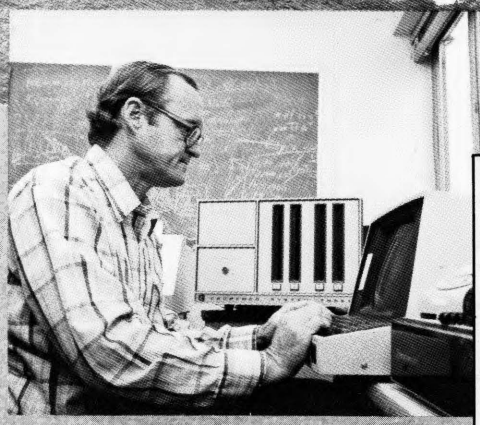
Dr. Jerome Namias, working with Daniel R. Cayan and Dr. Arthur V. Douglas, has pioneered the development of semi-objective synoptic techniques for seasonal prediction. These methods combine statistical and synoptic relationships and allow the forecaster to exercise judgment and incorporate physical understanding.

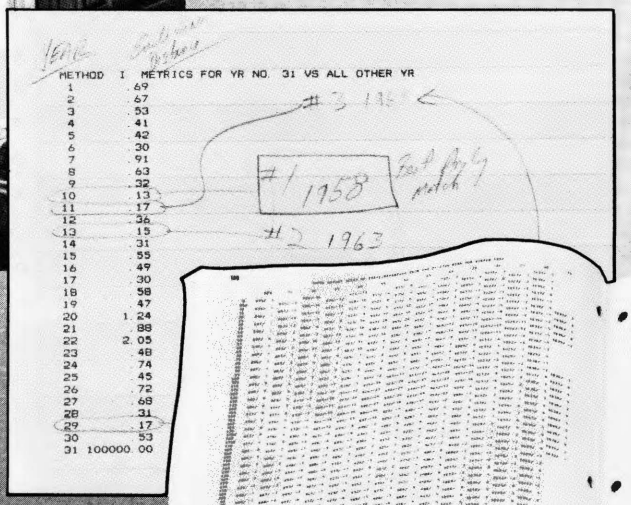
A recent first attempt by Drs. Namias and Douglas to increase the lead time of synoptic predictions yielded promising results. They made two forecasts for the 1980-1981 winter season, one in December at the beginning of the winter, and one three months earlier. Both predictions were successful. Aside from their immediate usefulness in making predictions, synoptic methods facilitate important statistical and dynamical improvements to forecasts.

In recent years, the group has developed several approaches to forecasting seasonal averages of temperature and precipitation. In each case, the goal has been to improve understanding of how certain aspects of the climate system work, and not simply to make predictions for their own sake.

Recognizing the value of this type of research, Congress, as part of the National Climate Program Act of 1978, authorized Experimental Climate Forecast Centers to develop and test such forecasting techniques. In 1981, the Climate Research Group was selected as the first such center and was awarded a grant by the National Oceanic and Atmospheric Administration (NOAA). Under the terms of the grant, seasonal forecasts using three different techniques will be prepared for each season in near-real time. The three techniques are Dr. Namias's synoptic method; a linear statistical algorithm developed by Dr. Barnett in collaboration with Dr. Klaus F. Hasselmann of Hamburg, West Germany; and an analogue procedure developed by Dr. Barnett together with Dr. Rudolph W. Preisendorfer of NOAA. By comparing the forecasts with one another and with observed conditions, the group hopes to improve the understanding of how the atmosphere and the ocean together create our climate.







METHOD I METRICS FOR YR NO. 31 VS ALL OTHER YR

1	.69
2	.67
3	.53
4	.41
5	.42
6	.30
7	.91
8	.63
9	.32
10	.13
11	.17
12	.36
13	.15
14	.31
15	.55
16	.49
17	.30
18	.58
19	.47
20	1.24
21	.88
22	2.05
23	.48
24	.74
25	.45
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29	.17
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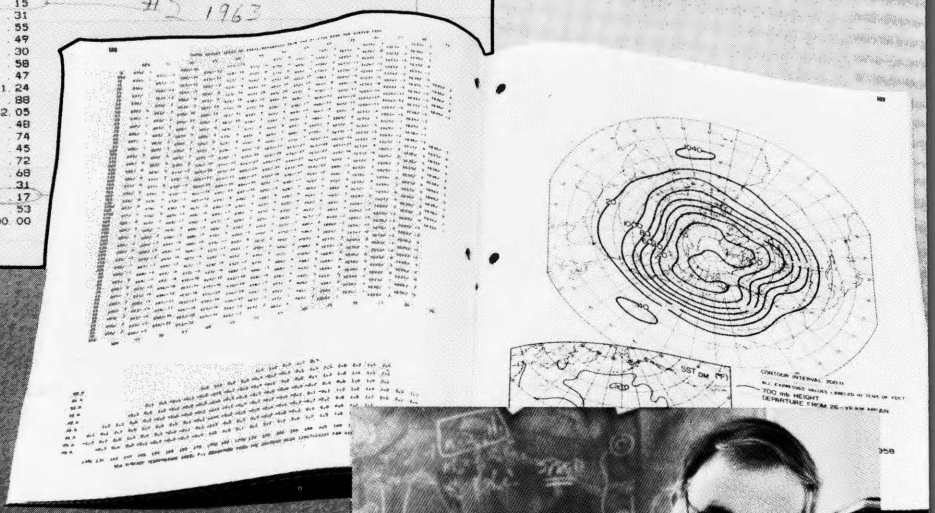
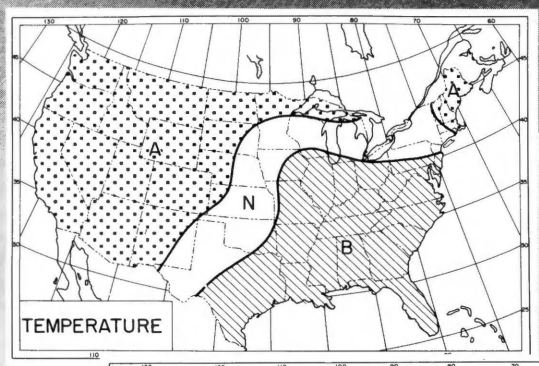
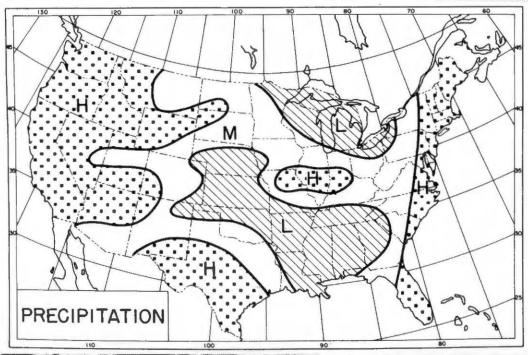
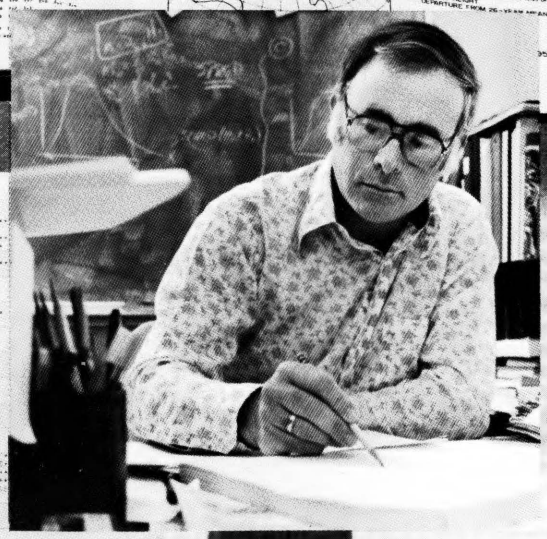
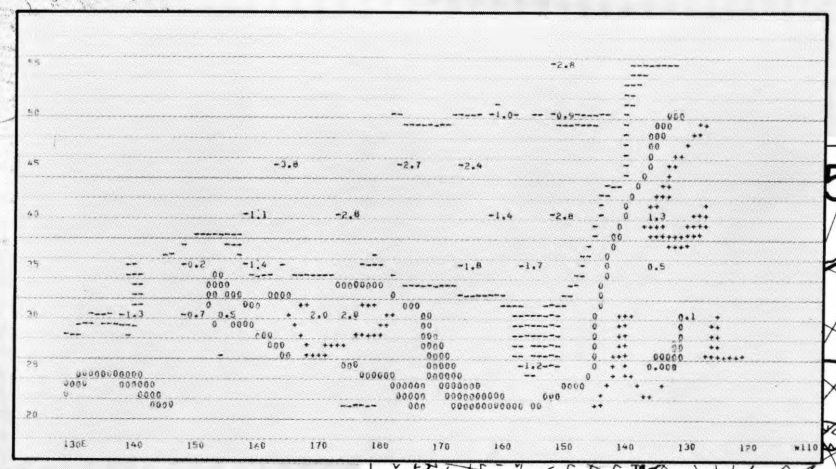


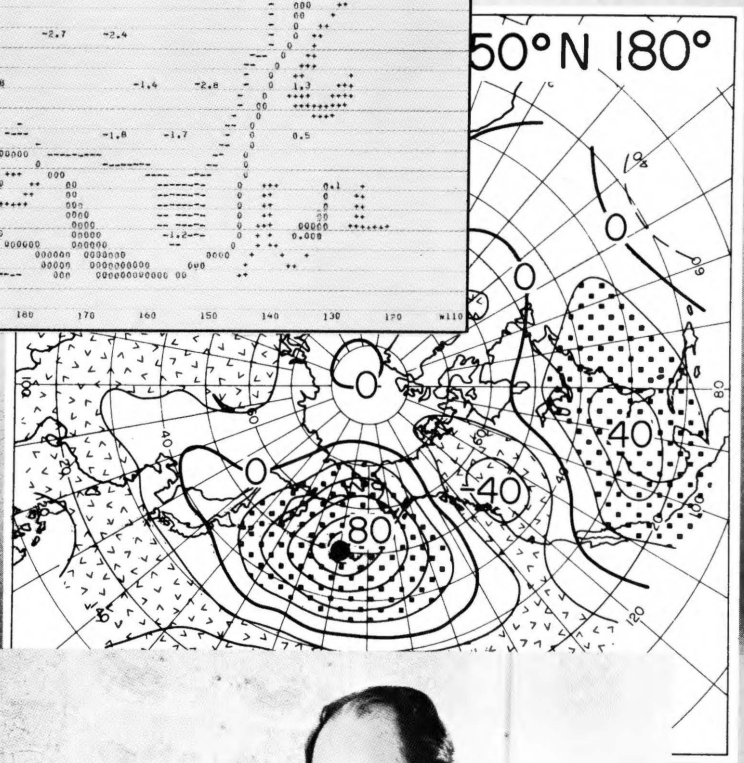


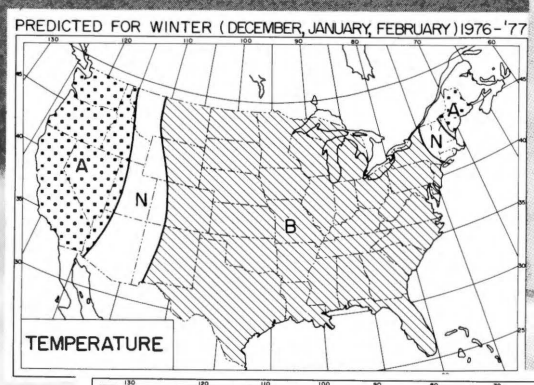


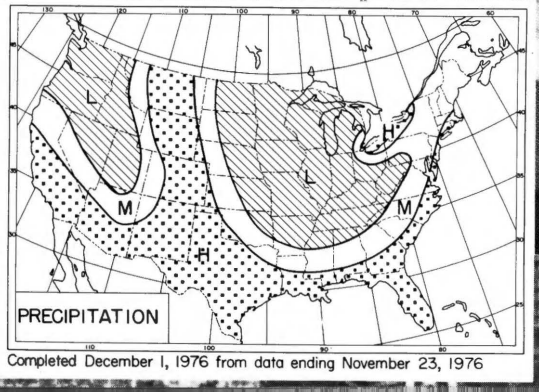


Two types of experimental forecasts done by the Climate Research Group are illustrated. At top left is a merchant ship that radios data that are compiled on tape and made available to scientists. These data are common to both prediction methods. Drs. Tim P. Barnett and Rudolph W. Preisendorfers' analog method is depicted at left. Shown at left from top down are: Tony M. Tubbs at computer, feeding sea-surface temperature data into an analog model; an output from an analog model; the CalCOFI Atlas #27 of historical atmospheric pressure patterns and sea-surface temperature by season; Dr. Barnett working on his prediction; a computer (map) printout of the analog year; and, finally, the analog prediction for the winter of 1976-1977. A few of the steps in the synoptic method used by Dr. Jerome Namias are demonstrated at top center and on the right. Shown here at top center is the projection of 1976-1977 winter 700 mb height anomalies from fall SST and 700 mb data; Marguerette S. Schultz analyzing the November 1976 700 mb height anomalies; sea-surface temperature anomalies for November 1976; winter teleconnections (cross-correlations) between 700 mb heights over the Aleutians and elsewhere over the Northern Hemisphere; Dr. Namias working on a prediction; and his predictions of temperature and precipitation for winter 1976-1977.









L. D. Ford

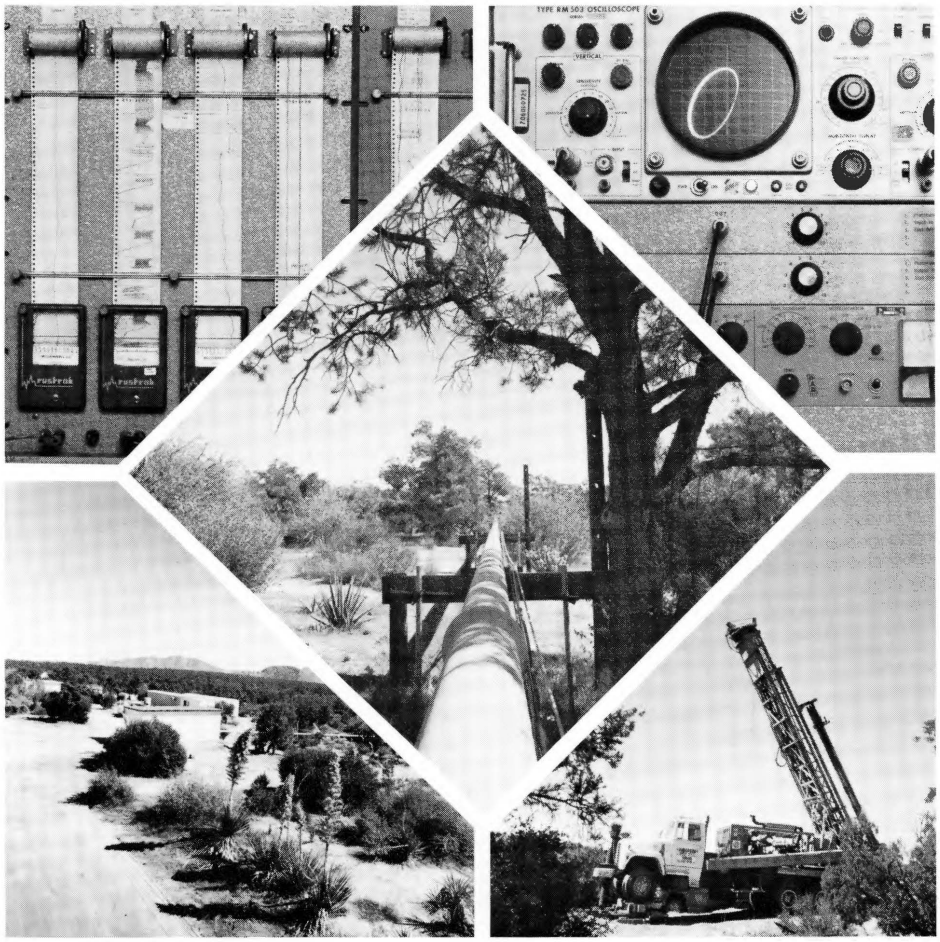
Cecil and Ida Green Piñon Flat Observatory

Earthquake territory: southern Caifornia's high rate of seismic activity provides a vast laboratory for geophysicists interested in earthquakes. Dr. Jonathan Berger and graduate student Frank K. Wyatt are studying the barely perceptible motions that accompany the slow tectonic movement of faults as well as the more rapid and devastating behavior that accompanies an earthquake. To measure these motions they have built a geophysical observatory in the high desert mountains south of Palm Springs—an area of unusually high seismic activity. Named after its benefactors, the Cecil and Ida Green Piñon Flat Observatory (PFO) has three basic research goals. The first is to develop new instrumentation and techniques to monitor both seismic and tectonic motions of the earth's crust. The second goal is to establish a reference station consisting of the most stable and sensitive instrumentation available so that an accurate estimate of surface deformation can be obtained and anomalous behavior can be distinguished from the normal. The third is to monitor the activity near the observatory, which is located in an area of unusually high seismic activity.

Over the past decade, PFO has been equipped with some of the most sophisticated geophysical instruments in the world. Three 731-m laser strain meters, a 535-m fluid tiltmeter, and a superconducting gravimeter are but a few of the more than 20 sensors that the UCSD team continuously operates at this site. In recent years, as interest in the seismotectonics of California has increased, other groups have availed themselves of PFO's facilities: currently research teams from UCLA, UC Santa Barbara, and four out-of-state institutions have ongoing experiments at PFO. The National Aeronautics and Space Administration uses PFO as a site for its Satellite Laser Ranging and portable Very Long Baseline Interferometry instruments, which are monitoring crustal movements of a 100 km to 1000 km scale. The U.S. Geological Survey monitors a geodetic trilateration network encompassing PFO; it uses laser ranging devices to measure distances between mountain tops and thus provides deformation data on the 10-30 km scale.

The theory of plate tectonics provides a convenient model to help unravel the complex motions of the earth's crust. In southern California, the main trace of the San Andreas fault, along which most of the motion between the North American and Pacific plates takes place, has been inactive during historic time. In contrast, the San Jacinto fault (an element of the San Andreas fault system) has experienced moderate earthquakes repeatedly, making it the most active fault in the state. Nearly the entire length has been broken by moderate earthquakes since the late nineteenth century. However, two obvious gaps have been left where earthquakes have not yet broken the fault. One of these is centered on the town of Anza in the high desert of Riverside County some 6 km from PFO. Here, the present high rate of microseismicity (earthquakes of magnitude 3 and smaller) leads one to expect more dramatic activity in the near future.

To monitor the seismic activity along this section of the fault, a new network is being installed. Digital telemetry will be used to send the data from the Anza area to Scripps via a microwave link atop Santa Rosa Mountain, overlooking PFO, with a repeater on Mt. Soledad in La Jolla. This network will provide Scripps scientists with a real-time view of the seismic activity along this critical section of the plate boundary and perhaps yield a better understanding of its rhythms.



Cecil and Ida Green Piñon Flat Observatory. At top left are crustal deformation records; at bottom left is the laser strain-meter facility. In the center is the strain-meter vacuum tubing used for an 800-m laser beam. At top right is a strain-meter interference pattern, and at bottom right is drilling equipment for a laser optical-anchor.

L. D. FORD

RESEARCH ACTIVITIES

A brief overview of the many scientific projects being conducted at Scripps is given in this Research Activities section. Support for the bulk of these projects has come from the National Science Foundation, Office of Naval Research, National Oceanic and Atmospheric Administration, Department of Energy, Department of the Army, and the National Institutes of Health.

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

Marine Life Research Group

The Marine Life Research Group (MLRG) has a special interest in the California Current and its bordering waters. Those studying marine life must take into consideration the environment in which things live, so in addition to biology, scientists in MLRG study physical oceanography, sedimentology, climatology, marine chemistry, and geology.

Community structure in the upper ocean is influenced by physical factors. Drs. Thomas L. Hayward, John A. McGowan, and Elizabeth L. Venrick, who have been studying the community structure of the central North Pacific environment for some time, embarked on a transect of the North Pacific Ocean from Hawaii directly north to the latitude of Coos Bay, Oregon. The physical structure of the water column, nutrients, chlorophyll, primary production, and zooplankton biomass were measured. The collected data show a south-to-north change in primary production and zooplankton biomass. This supports the hypothesis that spatial changes in the relation of the depth of an intrusion of low salinity water (the shallow salinity minimum) to the depth of the nutricline should result in spatial gradients in production and biological carrying capacity. Further examination of the data may reveal information about the relation between physical structure of the water column and the rate of vertical mixing, and the resultant supply of plant nutrients in the euphotic zone.

Dr. Venrick continues her work on the structural stability of the first trophic level—phytoplankton—in the North Pacific central environment. She has also undertaken a critical study of the Percent Similarity Index (PSI), a number often used as a measure of the similarity of the species composition of different communities or associations. A new expression has been derived that relates the similarity between replicate samples from a community to the heterogeneity within that association. The magnitude of this index is dependent upon the heterogeneity of the association, the number of species, their abundance, and their diversity, so appropriate use of the PSI depends on informed judgment.

Graduate student Paul C. Fiedler has completed a study of community patterns in the Southern California Bight, based on fine-scale sampling. He shows that some of the important grazers tend to avoid depths where red-tide organisms are abundant, thus reducing the mortality rate from grazing pressure and allowing those phytoplankters to "bloom."

The compilation of a time-series of satellite-derived images of the Southern California Bight has been completed by graduate student José Pelaez-Hudlet. These images show patterns of temperature and chlorophyll distributions over the bight area. Previously unknown patterns are now being analyzed.

Dr. Loren R. Haury has turned to the zooplankton biomass data presented in CalCOFI Atlases 13, 14, and 21 to analyze the size measurements of selected zooplankton groups. These analyses show how the size-frequency distributions of the zooplankton altered during a period when the conditions in the California Current changed from two years of abnormally cold water (1955-1956) to two years of abnormally warm water (1958-1959). These responses to physical as well as biotic factors could have important consequences for the successful reproduction and growth of planktivorous larval and adult fish.

Drs. James J. Simpson and Haury embarked on R/V *New Horizon* in January to study the physical dynamics, chemistry, and biology of a warm-core eddy embedded in the California Current. This 200-km-diameter eddy was detected prior to the cruise by infrared satellite imagery. The movement of this eddy was chronicled from satellite imagery by Dr. Chester J. Koblinsky during the cruise. Frequently, these real-time processed images were Telefax-transmitted to the ship to help plan the sampling of the eddy. Preliminary calculations show that the eddy has a dynamic height anomaly of 30 dyn. cm., comparable in energetics to many Gulf Stream rings in the Atlantic Ocean. Theoretical studies are in progress to determine whether or not a baroclinic instability mechanism, whereby potential energy is extracted from the mean flow and converted into eddy kinetic energy, is responsible for the eddy dynamics.

During the late austral summer of 1981, Dr. Edward Brinton and colleagues tracked and collected the large Antarctic shrimplike krill, *Euphausia superba*. These euphausiids were encountered in great swarms in the Scotia Sea, the Bransfield Strait, and along the Scotia Island Arc during a cruise of R/V *Melville*.

The swarms of adult and larval euphausiids extended over thousands of square kilometers, with mean densities in the range of 100 grams under a square meter of water. These euphausiids are fast-swimming nektonic animals. Their ability to avoid capture is evidenced by the disparity between sonar-estimated abundances and actual capture rates using nets. For example, the estimates of abundance using the nets were only about 0.4 percent of the estimates of abundance using sonar. One swarm being fished by a Russian trawler was estimated acoustically to have a bulk of 5 million metric tons, but the estimate from net hauls was only 20 thousand metric tons. These studies on *Euphausia superba* are exciting and will certainly contribute to a better understanding of the food and energy webs of the sea.

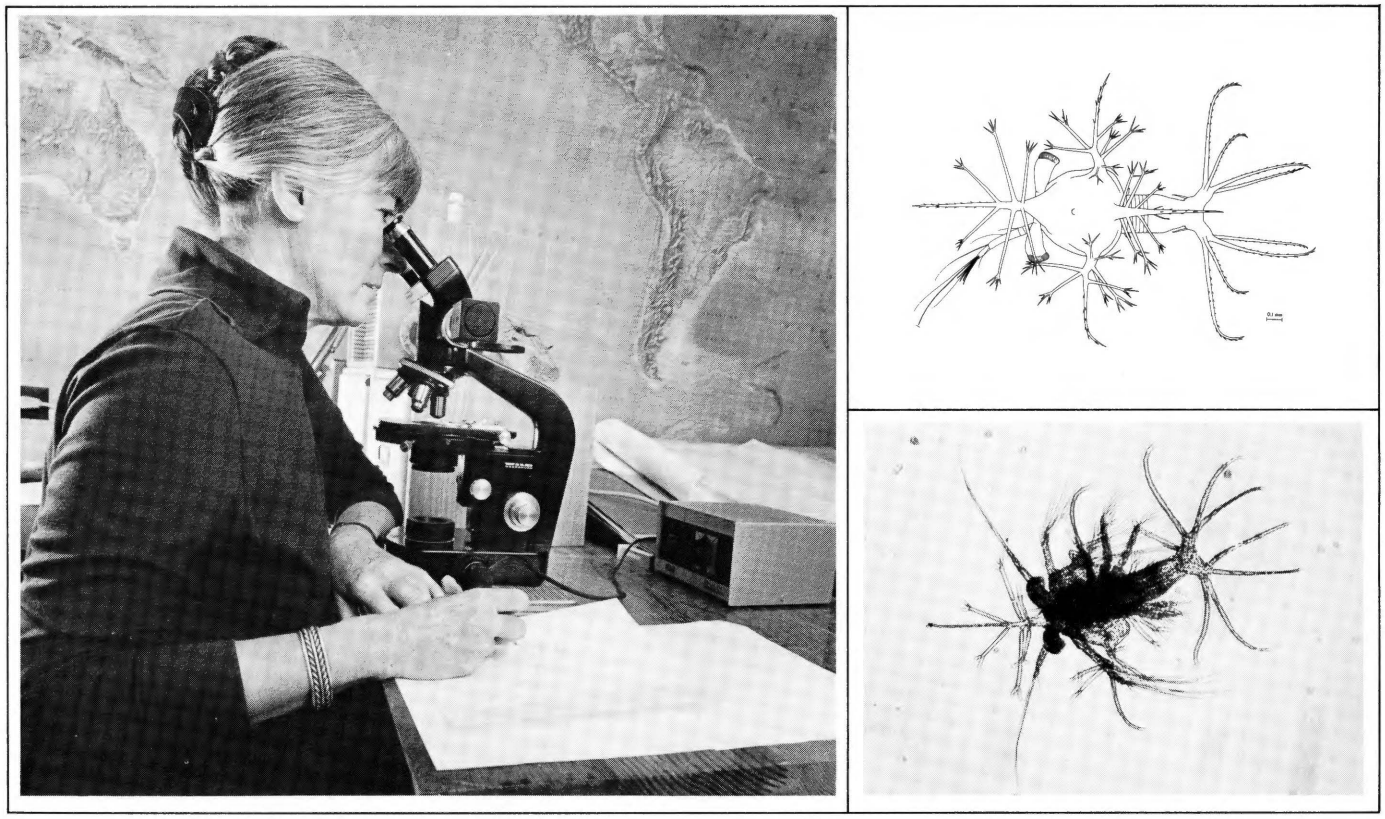
Margaret D. Knight has completed her description and illustration of the ontogeny of *Sergestes similis* Hansen, a marine shrimp. This work includes descriptions of the nauplius, protozoea, zoea, and early postlarval stages. These protozoeal forms are among the most elaborate of the larval decapods.

Dr. Martin W. Johnson continued his work on the systematics of the phyllosoma larvae of the palinurid, or spiny lobsters, and he is once again studying the distribution of the phyllosoma larvae of *Panulirus interruptus* from the California Current.

Dr. Abraham Fleminger continued to work on the four-year time series (1974-1977) of variation in inshore copepods typical of the Southern California Bight. Results so far suggest that seasonal variations are slight, despite evidence that there were incursions of Central and Equatorial waters during those years.

Dr. Fleminger also is continuing his work on patterns of morphological divergence in the copepod genus *Labidocera*. This is a circumglobal, low-latitude, relatively large, omnivorous and predatory genus, occupying the upper 5 m of the water column in coastal and neritic waters. Groups of closely related species tend to be distributed in a geographical sequence of ranges paralleling coastlines. Dr. Fleminger has recently discovered that Australasian lineages of *Labidocera* demonstrate biogeographical patterns analogous to Eastern Pacific (American) lineages. These results provide subjects for comparative analysis of independently evolving, phylogenetically related systems; this is a powerful inferential tool for field studies of evolution.

Tetsuo Matsui and Dr. Richard H. Rosenblatt have continued their work on the deep-sea fish family Searsiidae. Until recently, the presence of a lateral line in members of this family was thought to be a primitive or generalized condition, whereas its absence was thought to be the advanced or derived condition. The recent discovery of two forms with lateral lines, but otherwise manifesting advanced characteristics, leads to the con-



Margaret D. Knight prepares a drawing to illustrate the second protozoeal stage in the larval development of Sergestes similis. *At upper right is her drawing of this stage in dorsal view, and below is a photograph of the larva. This oceanic shrimp is one of the most common macroplankters in the North Pacific, and is abundant in the cooler waters of the California Current.*

clusion that the lateral line has been lost independently in several lineages. This discovery may be important in reevaluating relationships among these fishes.

Pontomyia is a genus of tiny (1.5 mm) flightless marine midges. Only four species are known from tropical seas around the world. The larvae remain submerged and feed on marine plants. Adults emerge onto the water surface and live for only 1-3 hours. Males propel themselves over the sea surface with oarlike wings while looking for females, which are wingless and virtually legless. By observing a laboratory population for 18 months, Dr. John Collins of James Cook University, Australia, and Dr. Lanna Cheng have learned that the adult emergence of *Pontomyia cottoni* is controlled by light: the males begin to emerge just before the end of the light period, but the females emerge only after the onset of darkness.

Joseph L. Reid has described the mid-depth circulation of the Pacific Ocean and its exchanges with the Atlantic and Indian oceans, as well as the mechanisms by which nutrients become highly concentrated, especially in the northeastern Pacific Ocean.

Graduate student Douglas A. Coats and Reid have studied the circulation of the great anticyclonic gyre of the upper North Pacific Ocean, based on calculations of potential vorticity. Reid has examined the pattern that describes the influence of the saline Mediterranean Sea outflow into the Atlantic upon the waters of the Norwegian-Greenland Sea. Dr. James H. Swift studied the outflow of the waters of the Norwegian-Greenland Sea into the Atlantic, where they contribute to the thermohaline circulation of the Atlantic ocean and the world oceans.

Dr. Charles S. Cox and collaborators have developed a Cartesian Diver that can be used to measure physical parameters of the water column along repeated vertical profiles. The instrument, in a pressure case, operates with varying buoyancy so that it alternately rises to the ocean surface and sinks to a predetermined depth. The diver was operated off Pt. Conception in November 1980, when it made 37 cycles (74 profiles in 38 hours) to a 240-m depth. The instrument records profiles of temperature and indications of water velocity. The horizontal velocity is inferred by the geomagnetic electrokinetographic method, and the vertical velocity is measured mechanically.

Daniel M. Brown has been tending the coastal tide gages at Catalina Island and San Clemente Island off the southern California coast for four years. A new stainless steel diaphragm design by Brown may result in a more reliable, maintenance-reduced tide gage for use in unprotected areas open to the full force of the sea. An experimental deployment of this tide gage will be made at San Nicolas Island, off southern California, thus permitting a tidal height time series to be collected on the seaward side of the Southern California Bight for the first time.

The 25-year daily coastal temperature time series continues to be provided by volunteer data collectors. MLRG provides thermometers to the collectors, who in turn provide one of the longest time series of daily Pacific coast sea temperatures.

An educational bibliographic exchange and assistance program with marine science institutions in Mexico has been expanded by Richard A. Schwartzlose and colleagues. More than 40 one-week guest-lecture tours in Baja California and a number of educational exchanges have been brought about through this program.

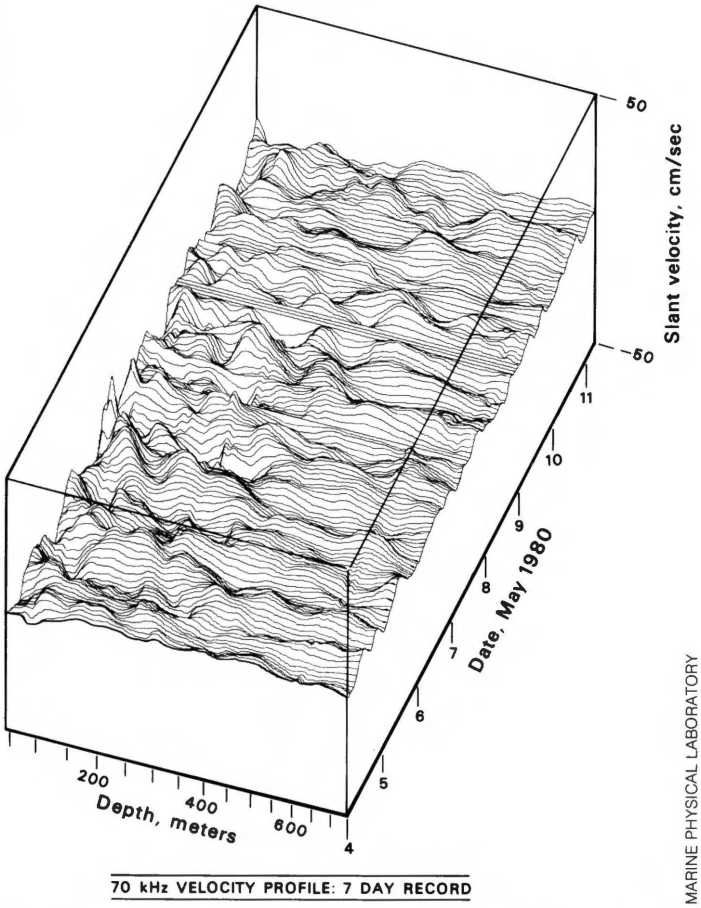
Marine Physical Laboratory

Ocean acoustics, marine geophysics, deep seabed studies, and marine technology are the principal areas of research at the Marine Physical Laboratory (MPL). This year MPL scientists, under the direction of Dr. Kenneth M. Watson, studied oceanic spreading centers, energy transport within the internal wave field, sound propagation in shallow water, and many other problems related to the physics of underwater acoustics.

Dr. Peter F. Lonsdale led two cruise legs in which unusual types of oceanic spreading centers in the Gulf of California and in the Mariana Trough were investigated with MPL's Deep Tow instrument system. In July, scientists aboard R/V *Melville* surveyed the sediment-swamped spreading centers in Guaymas Basin, where plate-boundary igneous activity is limited to dike and sill intrusion into the gulf's diatomaceous muds.

A highlight of this field program, which included detailed heat flow measurements plus hydrographic and geologic sampling, was the discovery an an active hydrothermal field where plumes of warm water issue from mineral deposits that have grown 20-30 m above the smooth, muddy sea floor. The sulfide, sulfate, and silicate minerals in these deposits are generally similar to those previously sampled from the East Pacific Rise crest at 21°N, though they occur in different proportions, and they are populated with colonies of the now-familiar "giant" vestimentiferan tube worms. A dredge recovered large masses of hydrothermal precipitates, including rich ores of zinc and copper, together with several intact, living (and hastily bottled or frozen) tube worms. A nearby sediment core provided equally dramatic evidence of shallow hydrothermal activity. It contained mineralized veins marking conduits for discharging water, and within 10 m of the seabed the plastic core liner had been partially melted by the great heat (>100°C).

The mineral deposits, hot-spring animals, and surrounding sediments were all coated or impregnated with a deisellike hydrocarbon; samples proved to be a condensate of petroleum that is formed at high temperatures as basaltic sills intrude the young organic-rich muds, and is transported to the sea floor by the hydrothermal circulation. MPL researchers hope that further study will clarify mechanisms of modern petroleum formation and migration, as well as processes of metallogenesis.



A seven-day sequence of velocity profiles from a 45° downward-slanting Doppler sonar beam shows the random nature of low-frequency internal waves that dominate the velocity field.

The second Deep Tow cruise was the first near-bottom study of a "back arc" spreading center, located behind the subduction zone of the Mariana Trench and its volcanic island arc. The structures proved to be like those on mid-ocean ridges of similar spreading rates, except that some segments of the back-arc ridge crest have unusually large volcanoes at their axes, and some are smothered in sediment derived from the island arc and therefore resemble the Gulf of California centers. Several hydrothermal vents were discovered along the ridge crest and at an off-axis site elsewhere in the Mariana Trough, but this time scientists were unable to photograph or sample any hot-spring animals.

Dr. William S. Hodgkiss, Jr., has been investigating the capability of adaptive array processors to cancel the unwanted surface reverberation from an active acoustic pulse. Boundary reverberation can be viewed as a narrow patch (in range) of reflected energy that changes position rapidly in time. Considering this patch as a mobile interference source leads to the application of adaptive array processing techniques. As an aid to understanding the temporal dynamics of the reverberation process, a computer-based reverberation model was completed with the aid of graduate student Joan M. Oltman.

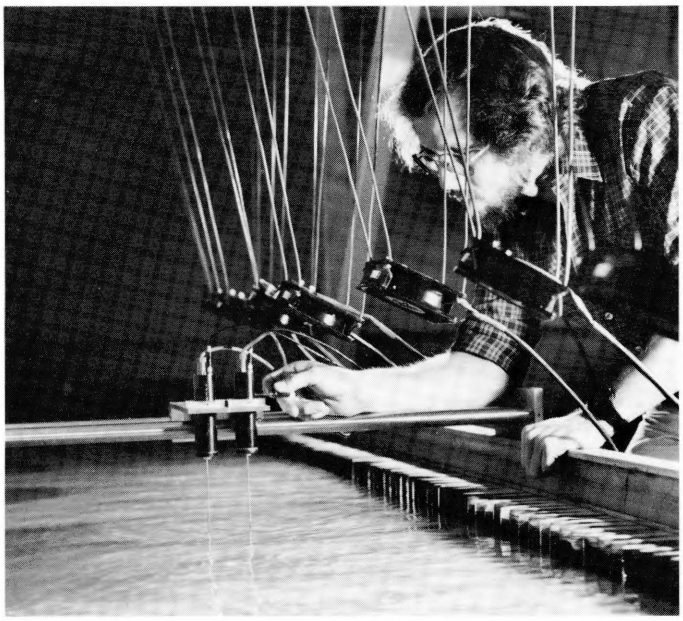
Doppler sonars use the perceived shift in carrier frequency between the outgoing pulse and the returning echo to estimate scatterer radial velocity at several ranges. Inherently, the problem is one of high-resolution (distinguishing small differences in velocity) spectral estimation across data segments (range bins) that are too short to provide the desired resolution via conventional methods of spectral analysis. In the Doppler sonar problem, scientists are studying the time-evolving (corresponding to range) spectral characteristics of echo. A similar situation is found in the area of speech processing, for example, where the resonant properties of the mouth cavity change as a function of time. With the aid of a graduate student, Dr. Hodgkiss has been investigating the characteristics of adaptive lattice structures for use in high-resolution spectral estimation.

Dr. Robert Pinkel's upper-ocean physics group analyzed data obtained with high-power Doppler sonars mounted on R/P FLIP as a technique for remotely sensing water motion. A sequence of velocity profiles taken over a seven-day period from a 45° downward-slanting sonar beam illustrated the random nature of the low-frequency internal waves that dominate the velocity field. There is more downward propagating energy than upward near the inertial frequency. Analysis of this data set is continuing, and preparations are under way for a FLIP cruise to investigate the dynamics of the mixed layer.

Dr. Robert B. Williams and Michael R. Layton have conducted theoretical normal mode studies of sound propagation in shallow water ducts with varying boundary conditions. A 12 m x 1 m x 10 cm tank has been constructed for experiments in conjunction with the theoretical work.

Oceanographic data obtained aboard R/V *New Horizon* during the Contrack V Expedition are being analyzed by Dr. Williams to evaluate the relationship of environmental effects to acoustic fluctuations. During a 1300-km sound source tow, XBT data were obtained every six hours (at 6 kts). From analysis of isotherm slopes Dr. Williams concluded that baroclinic modes were present.

Dr. Kenneth M. Watson and an associate continued studies of energy transport within the internal wavefield. Observations have been synthesized by Garret and Munk into a power spectrum having a simple analytic structure. In the high vertical wavenumber domain the Garrett-Munk spectrum of wave action (or vertical shear of horizontal velocity) is very nearly "white." The researchers have used the Taylor-Goldstein equation to analyze the flow of energy in this high wave number domain. The calculations indicate a "white" spectrum of wave action that rolls off at vertical wavelengths shorter than approximately 10 m. The calculations also indicate that the flux of internal wave energy into this short wavelength domain represents a



Michael R. Layton adjusts a receiver preamp used in scale-model studies of sound propagation in shallow seas.

significant part of the total energy budget of the internal wavefield.

Differential absorption measurement studies conducted by Drs. Frederick H. Fisher and Cheng-Chin Hsu have extended this work from ionic strengths of 0.12 up to 0.7 by adding 0.6 M NaCl to a 0.02 M $MgSO_4$ solution. Since the absorption is related solely to the concentration of $MgSO_4$ ion-pairs, the observed reduction as NaCl is added results from ionic strength effects on activity coefficients and from the formation of $MgCl^+$ and $NaSO_4^-$ ion-pairs.

Using the same 100-liter titanium resonator, Dr. Hsu has measured the effect of pressure on sound absorption in Lyman and Fleming seawater from 20 kHz to 300 kHz. Dr. Hsu's results up to 307 atm indicate a linear decrease with pressure (P in atm) in sound absorption, per wave length $\alpha\lambda$ according to the equation $\alpha\lambda(P)=\alpha\lambda(1)[1-8\times10^{-4}P]$. He finds the relaxation frequency to be independent of pressure at 139 ± 4 kHz.

Dr. Fisher and A. Peter Fox completed a study on the effect of pressure on conductance in NaCl solutions, which at infinite dilution displayed very nearly the same pressure dependence as observed in KCl solutions. Since these two ions have markedly different transport properties related to hydration effects, the similarity in pressure behavior was unexpected.

Dr. Fisher and associates have conducted work on stoichiometric association constants (K_A^*) for $MgSO_4$ in seawater, which argues for the value of $K_A^* = 11$ rather than $K_A^* = 41$ (Johnson and Pytkowicz). Their data in pure $MgSO_4$ solutions at high ionic strength support the lower value.

Dr. Robert C. Tyce's group developed a long, variable-depth, horizontal hydrophone array to be deployed from R/P FLIP for low-frequency ambient acoustic noise studies in the deep ocean. This effort will result in an array more than 1500 m long, with more than 200 hydrophones, and microprocessor telemetry for array navigation and in-array preprocessing of acoustic data.

Dr. Tyce's group also participated in studies of sediment and water column acoustics using FLIP off Monterey, California. Self-recording sea-floor hydrophones and a 20-element array suspended beneath FLIP were used to measure the low-frequency acoustic signals generated by charges detonated at 300 m and 2000 m by the USNS *Navajo,* and propagated both through the water column and thick (3 km) ocean sediments. This work was done in cooperation with Dr. George G. Shor, Jr., and Dr. Hodgkiss.

MPL scientists also constructed and operated a hydraulic assembly to be lowered through the hydrophone well on R/V *Thomas Washington.* The assembly included acoustic sources and sensors, television camera, and light to measure the noise and propagation losses caused by bubbles swept beneath the hull. With the assembly scientists demonstrated that swept-down bubbles can have a devastating impact on multibeam echosounding sonar performance, but that acceptable performance could be achieved for speeds under 9 knots and sea states less than 4.

Neurobiology Unit

The Neurobiology Unit, directed by Dr. Theodore H. Bullock, is part of the Marine Biomedical Program that enlists scientists from UC San Diego School of Medicine and Scripps in projects of joint interest to marine biology and medicine. Current studies center on the processing of sensory information, particularly from receptors in lower vertebrates.

Neuroethology is one of the themes of the laboratory. Researchers are using auditory brainstem response (ABR) to study hearing in vertebrates ranging from rays to porpoises. Laboratory scientists have found it eminently feasible to record these brain waves from porpoises. Evoked by ultrasonic clicks and picked up by noninvasive electrodes (needles under the skin, but not into the brain) these far-field potentials are detected many centimeters from the active auditory centers of the brain by computer averaging, which sums the potentials time-locked to the stimulus. Porpoises proved to have the same seven waves in the first ten milliseconds as humans, monkeys, cats, and rats—each peak with the same latency in the large-brained cetacean as in the small-brained rat. The porpoise's special adaptations were evident in the ultrasonic frequency range, in the maintenance of response up to high repetition rate, and in showing only one-tenth as much increase in latency with decrease of sound intensity as the human. The same method has permitted the first study of hearing in penguins, showing, for example, that high frequencies are much less effective than in humans. The ABR has been studied in elasomobranchs, holosteans, and cypriniform, siluriform, osteoglossiform, and perciform teleosts as well as in amphibians and reptiles.

A corresponding method is being used in a survey of fishes for the presence and quality of electroreception in many families and orders. This sensory modality turns out to be nearly general in the nonteleost groups (lampreys, sharks, ratfish, lungfish, bichirs, sturgeons, and coelacanths), but rare in the teleosts. The most recent—and surprising—discovery is electroreception in *Xenomystus,* a genus of knife fishes in the Notopteridae.

The neurobiology group also focuses on comparative neurology, inquiring into the evolution of the nervous system. They traced visual pathways of an elasmobranch by the HRP (horseradish peroxidase) axoplasmic transport method. A visiting scientist has followed the input from sense organs in the elasmobranch ear for position, acceleration, vibration, and acoustic stimulation into the first order nuclei of the medulla and up to midbrain, pretectal, and thalamic centers. He could show not only specific connections but differentiated dynamic properties. The findings represent a much higher degree of brain differentiation in this primitive group than had been known. Similar findings in the teleost were reported by scientists who recorded evoked potentials and single nerve cell activity in response to clicks and tones in a discrete area of the thalamus. They have also succeeded in applying the 2 deoxyglucose technique to fishes, to reveal the auditory centers of the elasmobranch brainstem and the teleost telencephalon. A discrete area in the catfish thalamus that receives later line mechanoreceptive input, using evoked potential and HRP techniques, was also localized.

The projection of the electroreceptive input into the cerebellum of siluriform fish has been worked out by the group. A visiting scientist has found, in the same fish, that stimulating the cerebellum modulates the potentials evoked in the midbrain by each of several sensory modalities, enhancing some and diminishing others. All these projects are contributing to a picture of the evolution of the vertebrate brain, in specified connections and in physiological properties.

Ocean Research Division

The Ocean Research Division (ORD) is the most diverse research division at Scripps, with research ranging from marine ecology to geophysical measurements.

This year's report is concentrated on a few areas of research within the division rather than on the work of each investigator. Marine ecology has centered mainly around Dr. Paul K. Dayton's group; Dr. Walter F. Heiligenberg discusses his behavioral and neurological studies of electric fish; Dr. Robert C. Finkel reports on new research directions of the Mt. Soledad Laboratory. Ocean physics investigations have included studies by Dr. Charles S. Cox's research group of the electrical conductivity of oceanic crustal rocks near the East Pacific Rise, and also studies of varying electromagnetic and pressure signals of the deep sea floor by Dr. Jean H. Filloux's group. Drs. Warren B. White, Robert L. Bernstein, and Gary A. Meyers report on the extended ocean monitoring system designed to yield information on the thermal structure of the upper 500 m in the Pacific Ocean. The widely known Physical and Chemical Oceanographic Data Facility (PACODF) has been active under the leadership of Robert T. Williams.

Though the above programs do not cover all research activities within ORD, this report represents its many research directions. In the Highlight sections Dr. Richard C. J. Somerville discusses the Climate Research Group's work. Others such as Dr. Charles D. Keeling's CO_2 research group have continued their efforts within the division. Future annual reports will concentrate on achievements by these groups.

Ecology

Several ecology projects are under way in Dr. Dayton's group. Dr. Mia J. Tegner is working on two large programs. The first study covers sea urchin natural history and population dynamics. It focuses on commercial exploitation and determination of the importance of interactions between sea urchins and other species to the structure of the kelp forest community. She has learned that the southern Channel Islands off the California coast have strongly bimodal sea urchin size frequency distributions, with high annual recruitment and poor survival of the second year class. The bimodality is consistent from year to year. In contrast, the northern Channel Islands have low and unpredictable recruitment, but higher survivorship of the second year class than in the south because predation appears to be less severe. In her second program, Dr. Tegner is studying the feasibility of enhancing abalone populations in depleted areas. The abalone project has demonstrated important early mortality from predation by octopuses, crabs, lobsters, cabezon and other fishes. Dr. Tegner's study has illustrated the role of larval ecology in the distribution and abundance of the local abalone species; it also suggests the importance of adequate nursery habitats to abalone populations. This research helps effect a multispecies approach to the management of all kelp bed resources.

Dr. Dayton is continuing his long-term study of the ecology of kelp forests at Pt. Loma, Santa Catalina Island, and Piedras Blancas off California. This study focuses on establishing dominance of hierarchies of the different canopy types as they relate to wave stress and competition for light. He has found that in semiexposed habitats the canopies floating on the surface are dominant, but as wave stress becomes increasingly important the lower canopies exert dominance. Dr. Dayton also demonstrated that these canopy types form patches in kelp forests that are resilient to change over many years. This resilience results from limited dispersal and strong competitive interaction. Dr. Dayton also continues evaluating data from his long-term Antarctic research program.

Graduate student Lisa A. Levin is studying the ecology of the infaunal community at the Kendall Frost Mission Bay Reserve in San Diego. She examined the life history and dispersal patterns of the dominant polychaete species on the mud flat in an effort to understand fluctuations in their abundance. In addition, she studied the mechanisms behind maintenance of dense assemblages of over 200,000 individuals per m^2. Parental care in the form of brooding seems to be the key to success for the infaunal species of Kendall Frost. Small-scale dispersal on the mud flat is studied using sediment trays and experimental manipulation of surface sediment. The water circulation within Mission Bay is being investigated in conjunction with larval distributions in order to understand local patterns of abundance and distribution. In addition, long-distance dispersal abilities of polychaete larvae are being evaluated. Drift bottles, drogues, and dye have been used to examine bay flushing patterns. Levin has also been studying intraspecific and interspecific behavioral interactions among surface-feeding polychaetes. For example, one species is highly territorial and seems to interfere with other species on the mud flat.

Janice E. Thompson, another graduate student with Dr. Dayton, has been studying the ecology of local, subtidal, sponge-dominated assemblages. She has investigated the species-specific defense mechanisms of sponges against local propagule settlement in an effort to understand how these adults hold space and protect it against nonresident invasion for long periods. Exuded allelochemicals seem responsible for the reduction in surface fouling of these individuals, and preliminary work suggests that combined chemical defenses, which result from close spatial proximity, may be even more effective.

A major part of Thompson's work involves collaboration with natural products chemists in an attempt to isolate and identify the exuded allelochemicals. Together they have isolated many novel and biologically active compounds. They have demonstrated field exudation into seawater of several toxic compounds at levels sufficient to reduce local propagule recruitment. Their work has also resulted in an understanding of the coevolution of sponge-specific predators. They have found that many dorid and pleurobranch nudibranchs selectively concentrate biologically active compounds obtained from specific sponge prey into their dorsa, glandular secretions, and egg cases.

Behavioral Science

The neuronal basis of simple behavioral responses in electric fish, with particular emphasis on central nervous mechanisms of sensory information processing, is studied by Dr. Heiligenberg's group. Given that certain behavioral response is elicited by a particular stimulus regime, which can be characterized by a number of physical variables, scientists first determine which stimulus variables are essential and which are irrelevant for control of the behavior. This is achieved by presenting artificial stimulus regimes in which any given stimulus variable can be modified at will.

After essential stimulus variables have been isolated, the next question is how the animal's nervous system computes these variables, and this in turn is answered by presenting them in combinations that normally do not occur. To the extent that scientists can then predictably confuse the animal, they have reasons to believe that their hypotheses about the computation of this sensory information are correct. In the case of the Jamming Avoidance Response of the weakly electric fish *Eigenmannia,* for example, they have found that this behavior is driven by joint modulations in the instantaneous phase and amplitude of the electric signal that results from the interference

of the animal's own electric organ discharges with those of a neighbor. These modulations are compared across different parts of the animal's body surface, and this distributed evaluation of temporal and spatial features of the stimulus regime allows the animal to determine in which direction its own electric organ discharge frequency must be shifted in order to move away from that of its neighbor.

After behavioral experiments have determined which types of algorithms the animal employs to evaluate a given stimulus pattern, scientists use neurophysiological and neuroanatomical methods to search for the neuronal hardware. How are essential stimulus variables encoded by sensory receptors, and how is their information transmitted to higher-order neurons in the central nervous system? What is the nature of the connections between such higher-order neurons that allows for the execution of the computational algorithms postulated by behavioral experiments? This research is largely facilitated by the fact that behaviors such as the Jamming Avoidance Response still function in neurophysiological preparations so that the role of given classes of neurons can more readily be determined. By then filling such neurons with chemical labels, such as Horseradish Peroxidase or Lucifer Yellow, the neuroanatomical fine-structure and the connections of such neurons can be determined. Ultimately, these scientists want to identify the whole network of neuronal events that controls behaviors such as the Jamming Avoidance Response, in the hope that the basic principles of sensory information processing will be discovered.

Mt. Soledad Laboratory

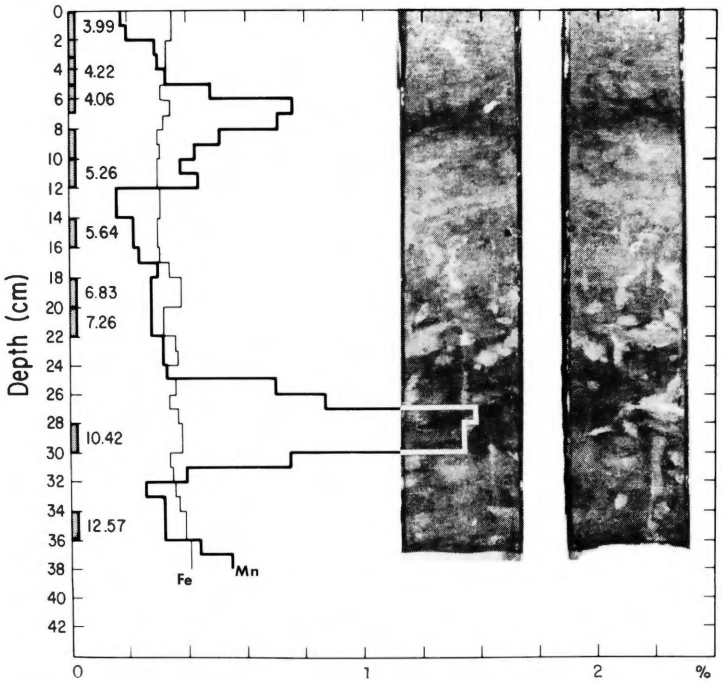
At the Mt. Soledad Laboratory, Dr. Finkel and colleagues have been using natural radioisotopes as tracers to study the geochemistry and chronology of mid-ocean ridge processes.

One of the major aspects of mid-ocean ridge activity is the production of new oceanic crust by the extrusion of basaltic magmas. Dr. J. Douglas Macdougall, Dr. Finkel, and graduate student Sally Newman have been studying chemical and isotopic variations in fresh mid-ocean ridge basalts collected along an 8-km section of the East Pacific Rise at 21°N. Low-level counting techniques were used to determine concentrations of U, Th, and Ra isotopes in samples of fresh glass, hand-picked to be free of any signs of alteration. Typically, samples collected within the central axis valley have $^{230}Th/^{238}U$ and $^{226}Ra/^{230}Th$ activity ratios that are greater than one. These radioisotope disequilibria confirm the youth of these ridge-crest rocks and, because isotopic equilibrium is expected in the upper-mantle source material of these basalts, there is the implication that the source material underwent chemical fractionation during or shortly prior to emplacement.

The $^{230}Th/^{232}Th$ activity ratio in the rocks, which is not affected by fractionation, provides a tool for determining the Th/U ratio in the mantle source material. The model Th/U ratio based on measurements at 21°N is 2.5-2.6, which is well below estimates of Th/U in the primitive mantle and shows that the source region for oceanic crust has been preferentially depleted in Th with respect to U. Comparison with Sr and Nd isotope measurements being carried out on the same basalts by Dr. Macdougall and Dr. Günter W. Lugmair suggests the possibility that the Th-U and Sr-Nd measurements may be combined to obtain information about the timing of fractionation events that occur during the formation of oceanic basalts.

A second aspect of mid-ocean ridges that is being investigated at the Mt. Soledad Laboratory is ridge crest hydrothermal circulation, which forms an important component of the marine geochemical cycle of many elements. Using alpha particle spectrometry, ^{238}U, ^{234}U, ^{210}Pb, and ^{210}Po have been measured in hydrothermal water samples collected at 21°N on the East Pacific Rise. These measurements have shown that uranium is depleted, and lead and polonium are significantly enriched in hydrothermal waters compared to ambient seawater.

In order to assess the significance of hydrothermal circulation it is necessary to have—in addition to concentration data—knowledge of the longevity of the hydrothermal vent fields. Initial results obtained at the Mt. Soledad Laboratory have shown that ^{210}Pb is an ideal chronometer species for study of ridge crest hydrothermal systems. Disequilibrium $^{210}Pb/^{226}Ra$ ratios, which have been observed in chimney material and associated sulfide sediments, suggest that the vents are relatively short-lived phenomena. Dr. Yu-chia Chung and graduate student Kyun Ryul Kim observed radial concentration gradients of ^{210}Pb in the wall of a black smoker chimney, which can be interpreted



At left is a graph of percent of manganese with respect to depth of core. Note the correlation between dark bands in the two core insets and the manganese spikes in the graph. At right, Dr. Wolfgang H. Berger counts foraminifera to test the hypothesis that the high manganese concentration near 30 cm in the core results from lowered ocean fertility 11,000 years ago, during deglaciation.

in terms of chimney growth rates. In order to determine detailed chronology of ridge crest hydrothermal deposits, this work is now being extended to include other U-Th series isotopes.

The recent history of hydrothermal circulation can be read in the edifices and sediments of the vent fields. To read the long-term history, Dr. Wolfgang H. Berger and Dr. Finkel are currently studying the metal deposition patterns in box cores of calcareous sediments from the western flank of the East Pacific Rise in the equatorial Pacific. Within the five cores studied to date, the depth profiles of manganese concentration show a sequence of peaks that can be correlated over a distance of more than 1000 km. Manganese accumulation rates are about ten times higher than is normal over the deep ocean. Iron accumulation rates are high also, and decrease monotonically with increasing distance from the ridge crest. Work is currently under way to interpret these patterns, which are the result of a complex mixture of diagenesis, changing water-column productivity, ridge crest injection of hydrothermal fluids, and post-depositional migration.

Marine Physics

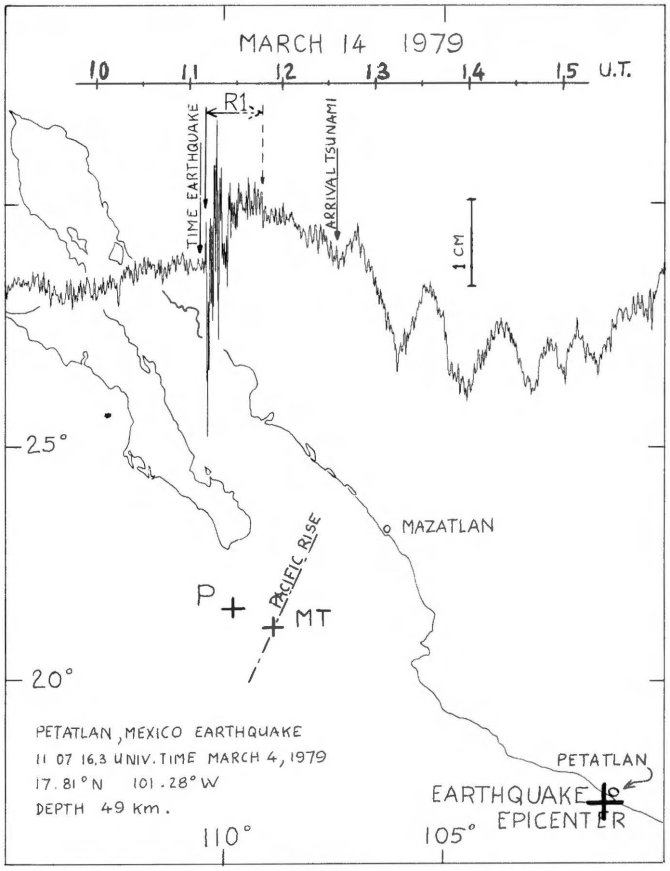
The ocean acts as a thick, conducting slab that tends to freeze in the lines of force of the earth's magnetic field. Therefore, when there is relative motion between the water and the underlying rock, the magnetic lines of force tend to remain fixed in the water and are dragged through the rocks. If an electric field recorder, consisting of a horizontal antenna and voltmeter, is fixed to the sea floor, the resulting motion of the magnetic field lines will cut across the antenna wire and induce a measurable voltage. Therefore a seismic disturbance, sweeping as a wave through the crust of the earth and causing relative motion between water and rock, will generate electrical signals in a sea-floor voltmeter. Theoretical studies by graduate student Spahr C. Webb and Dr. Charles S. Cox show that the signals will perhaps make for more sensitive detection than conventional seismometers for surface waves.

The conductivity of crustal rocks near the East Pacific Rise at 21°N has been examined by Drs. Peter D. Young and Cox. Here measurements were made in 1979 by applying a remote sounding technique in which electromagnetic signals were injected into the crust from a ship-powered transmitter on the sea floor. The signals were picked up by a detector also on the sea floor after propagating a distance of 19 km through the crust. The center of the propagation path was 14 km from the spreading axis of the East Pacific Rise.

In general, electromagnetic signals propagate most effectively through a highly resistive medium and at the lowest frequencies. The fact that signals with frequencies up to 2.25 Hz were detected indicates that the lower crust is at least ten times more resistive than the basaltic, upper crust where direct measurements have been made. This result implies that no extensive magma chamber interrupted the path of propagation, because magma has a very low resistivity—about that of seawater. On the other hand, the resistivity is not as low as that of dry, hot but solid rock unless its temperature exceeds 700°C. These results are consistent with a model in which the electrical conductance of the upper crust derives almost entirely from seawater-filled cracks and pores. Below the basalt the permeability to water flow is small but finite. Finally, in the lower crust where the rocks are very hot, mineral conductivity becomes dominant.

Dr. Filloux and his group observe natural deep sea-floor electromagnetic variations and pressure signals to gain information on electrical conductivity and structure of the upper mantle and on large-scale oceanic motions. Observation periods exceeding four months have been achieved with arrays that included simultaneously 26 instruments.

A recent magnetotelluric (MT) array across the Pacific Rise at 21°10′N included observations centered exactly on the spreading axis. These data suggest the existence, though re-



DR. J. H. FILLOUX

Location of the observation stations: MT, magnetotellurics; P, pressure; and the Petatlan earthquake epicenter. The signals received by the pressure sensor are shown on the upper half with a 1-cm scale equivalent sea-level elevation. The timing of the earthquake, the first seismic signals (Rayleigh R1), and the tsunami arrival are also shown.

stricted to the very near vicinity of the ridge crest, of a shallow, exceedingly conductive layer (conductance: 3500 S.) equivalent to several kilometers of molten basalt, extending laterally 10 to 20 km. This feature is consistent with the postulated association of shallow magma chambers on the axis of oceanic spreading ridges.

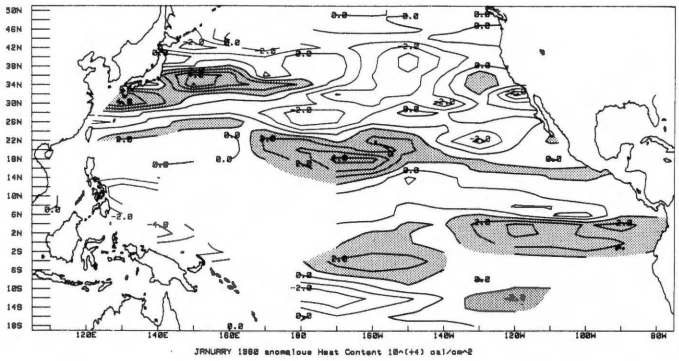
During the same experiment, a large earthquake (magnitude 7.4) occurred slightly offshore of Mexico and generated a long ocean wave (tsunami) which, for the first time, was recorded in deep water.

More recently, investigation of very old sea floor and subducting lithosphere has been undertaken jointly with colleagues at the Earthquake Research Institute and at the Ocean Research Institute of the University of Tokyo, Japan. This program was conducted from the R/V *Hakuho-Maru* of the Ocean Research Institute.

Ocean Monitoring System

During the past five years, Drs. White, Bernstein, and Meyers have conducted a pilot ocean monitoring program with volunteer observing ships transecting the Pacific Ocean from North America and South America to Asia and Australia. Placed aboard each of these ships is an expendable bathythermograph (XBT) system from which the thermal structure over the upper 500 m of ocean is profiled 2-4 times daily. Data gathered from all ships facilitated monthly construction of subsurface maps of temperature over the Pacific, on both a regional and basin-wide scale.

Last year, the pilot phase of the ocean monitoring program ended and was replaced by an operational program with routine production of both regional and basin-wide maps of



DR. W. B. WHITE

Data gathered from volunteer observing ships are used to construct monthly subsurface maps of temperature over the Pacific on both a regional and basin-wide scale.

subsurface temperature. This mapping capability allows, for the first time, investigation into the month-to-month and year-to-year variability of the large-scale general circulation and heat content of the Pacific. This has direct application to research on short-term, ocean/atmosphere climate variability. Other benefits accrue to ocean fishing forecasting and ocean pollution prediction.

A virtual scientific bonanza has emanated from the pilot phase of this program. In the mid-latitude North Pacific, the mean structure of the North Pacific current was found to consist of zonal bands of relatively high-speed flow (for example, 10 cm/sec) separated by zonal regions of little mean flow, but enhanced eddy activity. Moreover, baroclinic long waves (1000-km wavelengths) were observed to propagate westward in the main thermocline, emanating from the coast of North America. In the Kuroshio Extension, east of Japan, determination of the potential energy interaction between mean flow and eddy flow indicated that much of the poleward transport of heat in the ocean at mid-latitude results from horizontal turbulent exchange. In the tropical Pacific, westward-propagating long waves (5000 km wavelengths) have been observed and their source investigated. These waves significantly alter sea level and heat content in the tropics and may play an important role in regional and global climate variability.

Physical and Chemical Oceanographic Data Facility

The Physical and Chemical Oceanographic Data Facility has been involved with the Transient Tracers in the Ocean (TTO) study in the North Atlantic, and the triennial California Cooperative Oceanic Fisheries Investigations in the California Current system. The seagoing phase of both programs began in the fall of 1980. The CalCOFI work involved two ships, R/V *David Starr Jordan* and R/V *New Horizon.*

PACODF personnel engaged in several short expeditions in addition to CalCOFI and TTO, and work continues on the GEOSECS Atlas series. The volume presenting graphics from the Atlantic expedition has been published and distributed, and several other volumes are in preparation.

During the last few months, PACODF completed its participation in the NORPAX "Hawaii-Tahiti Shuttle Experiment," with the publication of a 15-volume CTD data report and a 4-volume hydrographic data report. This program consisted of 15 one-month voyages between Hawaii and Tahiti, which generated an immense quantity of hydrographic, meteorological, geochemical, and biological data in the Pacific equatorial current system.

Physiological Research Laboratory

The physiological and biochemical adaptations of aquatic and terrestrial animals to their environment constitute a central research theme at the Physiological Research Laboratory (PRL). Laboratory scientists engage in cooperative projects with the UC San Diego School of Medicine and other domestic and foreign institutions.

Studies of free-ranging behavior and physiology of marine mammals were continued by Dr. Gerald L. Kooyman's group. A comparative study of selected enzyme systems in marine and terrestrial mammals was completed by Dr. Michael A. Castellini. Dr. Daniel P. Costa has evaluated the energetic cost of milk production by mother elephant seals and the efficiency of energy transfer to nursing pups. Dr Kooyman's group also completed three extended field studies of diving behavior in seals and sea lions. These studies reveal time-depth profiles in free-ranging animals in the tropics and southern polar areas. The Antarctic study continues through the efforts of PRL's first overwintering team. The combination of laboratory and field observations is providing a better understanding of the type of fuel used during diving, of the overall energy requirements, and of the effort required to obtain sufficient food.

Dr. Harold T. Hammel and two West German colleagues continue to investigate the properties of body fluids that influence salt gland secretion in marine birds. They recently demonstrated that the ion concentration of blood flowing to the head influences the secretion rate of the salt glands. Dr. Hammel and James E. Maggert gathered evidence suggesting that alterations in extracellular fluid volume influence salt excretion more powerfully than changes in osmolality of body fluids. Also in Dr. Hammel's laboratory Dr. Martha E. Heath is evaluating the role of thermosensitivity of the rostral brainstem in thermoregulation of the armadillo. She has demonstrated that selective cooling of hypothalamic nuclei induces shivering and increases the rate of heat production in conscious animals. Other experiments suggest a lack of sensitivity to alterations in core temperature.

Dr. Ralph A. Ackerman is investigating the relationship between avian body temperature regulation and the control of egg temperature during incubation. He substituted copper eggs, which were accepted by the incubating Adélie penguins at the Hubbs-Sea World Research Institute, San Diego. Temperature was varied by heating and cooling the water that flowed through the copper eggs. Measurement of heat production by the incubating adult and its thermal responses were measured as a function of egg temperature. The results indicate that incubating Adélie penguins are sensitive to alterations in the brood patch/egg temperature gradient and that they adjust heat production and body contact to regulate egg temperature.

Studies of the respiratory adaptations of the facultative water and air-breathing swamp eel *Synbranchus* continue in the laboratory of Dr. Jeffrey B. Graham. The eels live in mud burrows during periods of low rainfall. Field observations in Panama and studies in the laboratory reveal a lower respiratory production of carbon dioxide than expected during air breathing in mud burrows or in glass tubes. Excessive accumulation of CO_2 in burrows would be expected to negatively impact oxygen utilization. Dr. Graham finds that the fish is capable of shunting much of the metabolically produced CO_2 to the urine in the form of bicarbonate. The capacious urinary bladder can reabsorb much of the urinary water; the result is a concentrated urine rich in bicarbonate. Graduate student Kathryn A. Dickson and Dr. Graham completed their study of thermoregulation in albacore tuna, one of the warm-blooded fishes. While on board R/V *David Starr Jordan,* they determined that the albacore uses physiological mechanisms to control heat loss and gain and is able to defend a deep body temperature of about 20°C even while swimming in water as cold as 11°C. Dickson is also investigating the physiology and biochemistry of scombrid swimming muscle in relationship to high performance swimming and tuna endothermy.

Circadian rhythms in activity and metabolism are widespread in animals. Studies in the laboratory of Dr. Fred N. White reveal that some lower vertebrates, during behavioral sleep, retain carbon dioxide relative to the active phase of the diurnal cycle.

A similar phenomenon occurs in sleeping humans. In sleeping reptiles, the CO_2 retention is rapidly reversed by administration of the opiate antagonist drug, Naloxone. This suggests that naturally produced opiates (similar in action to morphine) are involved in resetting respiratory sensitivity to carbon dioxide. Experiments in collaboration with Drs. Roger G. Spragg and David M. Burns, UC San Diego School of Medicine, are being conducted to evaluate the relevance of these findings to sleeping humans. Drs. Yitzhak Weinstein and White have recently demonstrated that the degree of carbon dioxide retention associated with sleep is capable of reducing the total energy requirements of lower vertebrates by around 15 percent below waking basal levels. The findings focus attention on carbon dioxide as a modulator of metabolic intensity.

Graduate student Patrick M. McDonough uses a pressure chamber to study the nature of bubble formation in marine organisms undergoing decompression. Here he is testing a ghost shrimp Callianassa affinis *(inset upper right).*

Dr. Edvard A. Hemmingsen and graduate student Patrick M. McDonough continued their investigations of gas bubble nucleation in biological fluids, single cells, and primitive organisms to better understand the early etiology of decompression sickness. One objective is to assess the notion that preformed gaseous nuclei may play a role in initiating bubbles in organisms. The results obtained indicate that such nuclei are far less prevalent than generally assumed.

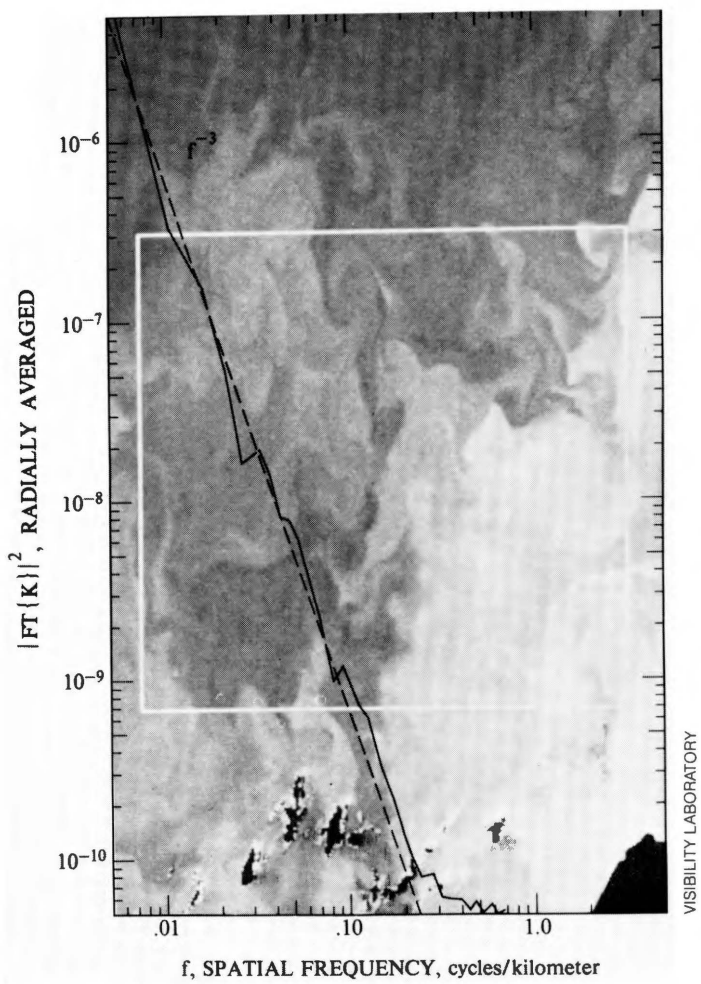
Life processes in the deep sea remain the central theme in the laboratory of Dr. A. Aristides Yayanos. In recent years, the culture collection of deep-sea bacteria has been expanded to contain organisms from 2, 3.8, 5.7, 7, 8, 9, and 10.5 thousand meters. Cultures are maintained in the laboratory in pressure vessels that simulate the pressures of the bacteria's natural environment. The samples originate from the San Clemente Basin, the Philippine Trench, and the Mariana Trench. The trenches were sampled in November 1980 from R/V *Thomas Washington* during the Rama Expedition. Research on amphipods showed progress in two major ways. First, animals from 2,000 m were maintained in the laboratory for 6 months. Second, live amphipods were retrieved from the deepest spot of the Mariana Trench with the use of pressure-retaining traps. These achievements will speed progress in learning about life processes in the deepest reaches of the ocean.

Visibility Laboratory

Scientists at the Visibility Laboratory conduct research in a variety of areas involving the optics of the atmospheric and oceanic environment, optical remote sensing, and digital processing of image information.

The application of optical remote sensing to the study of ocean processes and properties is a major activity of the laboratory. Researchers use data from the Coastal Zone Color Scanner (CZCS) carried on the NIMBUS-7 satellite. Roswell W. Austin, as a member of the NASA (National Aeronautics and Space Administration) experiment team for this sensor, continued the development and validation of the various data-processing algorithms.

Scientists continued developing a data base of ocean optical properties. Current emphasis is on compiling a computer library of the optical attenuation properties of ocean waters accessible by latitude, longitude, and season. Input for the data base is the water attenuation as derived from the CZCS images. Benjamin L. McGlamery is using image-processing techniques to investigate the spatial variations of the attenuation fields. The observed variations are in part caused by actual variations in the optical properties of the water and in part by the sensor



The image is a two-dimensional map of the diffuse attenuation coefficient (K) of the waters of the northwest coast of Africa taken from CZCS data. The box indicates the region over which a two-dimensional power spectrum was made. The graph shows the radially averaged power spectrum that follows a power law out to spatial frequencies at which sensor noise dominates. Information such as this will be used to optimize the design of a computer-based library of optical properties of ocean water.

(CZCS) noise, which is accentuated by the atmospheric correction process. To determine the optimum data storage resolution, the spatial frequency characteristics of the attenuation field and of the sensor-induced noise are being examined.

Dr. Raymond C. Smith and Karen S. Baker have investigated using the distribution of chlorophyll as derived from the CZCS images to study primary production in the ocean. Together with Dr. Richard W. Eppley, they learned that combining satellite (CZCS) and shipboard measurements permitted the synoptic assessment of productivity and study of its two-dimensional variability, which was not possible from ship measurements alone.

Austin is using data from the CZCS, obtained at the Scripps Satellite-Oceanography Facility, to provide ocean color boundary information as a part of a demonstration of how satellite-derived data can aid West Coast fisheries. This is a component of the Fisheries Demonstration Program sponsored by NASA and Jet Propulsion Laboratory in Pasadena, California, to provide various fisheries with helpful meteorological and oceanographic data.

Studies by Richard W. Johnson and staff continued in several areas related to atmospheric effects on the propagation of visible and infrared radiation through the lower troposphere. They are studying the relationships between the simultaneous measurements of extinction coefficients at visible and infrared wavelengths, the characteristic distributions of atmospheric aerosols, and the development of operationally efficient models for multispectral atmospheric contrast transmittance.

A year-long series of hourly measurements of surface atmospheric extinction coefficients has been studied by Janet E. Shields. She is trying to establish the relationships between visible and infrared extinctions and their comparability with modeled predictions. Her studies indicate generally close comparisons with the LOWTRAN computer code under clear or hazy conditions. In fog, however, there is a significant need for improved monitoring and model performances.

Dr. Bruce W. Fitch has expanded his study of tropospheric aerosol size distributions and their occurrence as a function of altitude to include the entire data base gathered from 650 aircraft flights. This research includes developing multimodel fits to the measured data, and the relationships between the model fit parameters and simultaneous measurements of selected atmospheric optical and meteorological properties.

Wayne S. Hering has refined and validated his visible spectrum contrast transmittance model, which addresses both multiple scattering effects and variations in aerosol scattering as a function of changing altitude. This model for forecasting the variations in atmospheric contrast transmittance has been validated against both the Visibility Laboratory's field measurements and the standards established by the International Association of Meteorology and Atmospheric Physics. Results have been positive under a range of atmospheric conditions. The code is fast running and is being modified to handle computations for absorbing atmospheres more efficiently.

Scientists anticipate that these studies will continue to promote improved analytic links between observed meteorology and the optical state of the atmosphere.

Center for Coastal Studies

The Center for Coastal Studies acts as a focus for research and teaching in shore and coastal processes and mariné archaeology. The center, directed by Dr. Douglas L. Inman, is composed of five groups: the Shore Processes Study Group, the Coastal Ocean Dynamics Experiment, the Innovative Sediment Management Program, the Marine Archaeology Program, and the Hydraulics Laboratory.

Research at the center varies from basic to applied, local to foreign, and on scales from clay particle interactions to satellite maps of shelf circulation. Scientists at the center are also increasingly involved in local sediment management and beach erosion studies and planning.

A project was initiated this year—funded by the Department of State, Agency for International Development—to study beach and coastal processes in the Nile Delta Littoral Cell. The cell extends from Alexandria, Egypt, to northern Israel, and thus provides a natural basis for cooperative U.S., Israeli, and Egyptian work. A planning conference, attended by delegates from Egypt, Israel, and the U.S., was held at Scripps in August 1980.

A study has begun to plan a sand bypass system for Oceanside, California. The beaches south of the Camp Pendleton/Oceanside Harbor complex have suffered erosion since the boat basin at Camp Pendleton was constructed in 1943. The sediment supply problem has been exacerbated by flood control measures in the local rivers, and recent severe winter storms have increased the alongshore and onshore-offshore transport of sand. A solution to this local erosion problem must include a system to bypass sand around the harbor complex. The operation of such a system must furthermore recognize the complex factors of seasonal beach cycles, as well as long-term climatic effects on the supply of sand. Finally, the effects of local erosion mitigation on the areas down coast must be carefully assessed.

A second local study was undertaken to monitor and document the performance of the "Longard Tube" experimental revetment installed between 27th and 29th streets in Del Mar, California. This 200-m plastic tube was buried in the backshore of the beach in December 1980 to contain the sand behind it. The performance evaluation of the structure will be based on beach profile measurements, wave observations, and surveys of the tube. Profile measurements on the entire Del Mar beach have been under way since 1974. These data provide important background for the project.

CENTER FOR COASTAL STUDIES

The south end of the Longard Tube on the beach in Del Mar. The plastic tube is 2 m in diameter and is filled with sand.

CENTER FOR COASTAL STUDIES

The tube in place at the north end of Del Mar. Center for Coastal Studies scientists are gathering data to attempt to evaluate the tube as an inexpensive alternative to a seawall.

The continental shelf circulation off northern California is being studied as part of the multiuniversity Coastal Ocean Dynamics Experiment (CODE). This is the most heavily instrumented coastal circulation study ever. Twelve pressure sensors, four thermistor chains, and fifty vector-measuring current meters are being deployed on ten moorings for periods betweeen four and six months to detail the currents and temperature structure on scales from 5 to 150 km. Other agencies and university investigators are carrying out coordinated aircraft overflights, ship operations to measure temperature and density fields, and sea surface drifter experiments. As part of this experiment, infrared images of the CODE area are collected and processed at the Scripps Satellite-Oceanography Facility. Satellite-derived sea-surface temperature maps will be calibrated by comparison with CODE data. The satellite images will be used to interpret the spatial structure of temperature features and the effect of deep-ocean velocity structures on the shelf circulation.

The Innovative Sediment Management Program has had major successes in design, fabrication, and deployment of experimental prototype sediment barrier curtains and scouring jets at Mare Island Naval Shipyard, Vallejo, California; in fluid-sediment dynamics studies at Mayport Naval Station in Florida; and in advising the Navy on waterfront design problems at Kings Bay, Georgia. Removable curtain barriers are effective in controlling fine sediment accumulation in finger pier berthing areas on the Napa River off San Pablo Bay, California. High-velocity water scour jets protect quay wall docking facilities from excess silt accumulation. The extreme drought conditions of 1976-1977 contrasted by the very wet years of 1978 and 1980 provided the maximum range of sediment discharge and shoaling rates likely to be encountered. This wide variation over five years makes possible the engineering design of these curtains and jet arrays for almost any harbor.

A second major effort of the sediment management program was a field study of the dynamic mechanisms responsible for shoaling at the Mayport Naval Station. Current-meter measurements, sea-level observations, and dye streaks photographed from the air showed that a combination of Bernoulli suction and strong interface eddies formed on the boundary between the inflowing seawater and the outflowing St. Johns River water were responsible for the excessive silt transport. Means to eliminate the suction induced by sea-level differences and the eddies are being studied.

A major flow channel that will considerably enhance the research capabilities of the Scripps Hydraulics Laboratory has been designed and is under construction. The Fleischmann Foundation provided funds for this large, homogeneous and stratified flow channel. John D. Powell, Hydraulics Laboratory supervisor, designed the channel, which is being constructed by an augmented laboratory staff. The flow cross-section will be 1.1 m^2 and will consist of two layers with velocities variable to 1.2 m/s. The glass-sided channel test section is 16 m long and can be tilted 1° along its length. There will also be automatic control of flow velocity and temperature and salinity of each layer.

The Marine Archaeology Program organized an international, multidisciplinary symposium held at Scripps: "Quaternary Land-Sea Migration Bridges and Human Occupation of Submerged Coastlines." The first systematic, scientific collecting and curating project has been established to map and preserve offshore artifacts in the southern California coastal waters.

Deep Sea Drilling Project

The oldest rocks ever recovered from the deep sea were taken this year by scientists aboard research vessel *Glomar Challenger*. These rocks, buried beneath a 2.5 km-thick accumulation of younger sediment (500 km east of Fort Lauderdale, Florida) are 145-155 million years old.

DEEP SEA DRILLING PROJECT

Global Marine and DSDP personnel breaking out pressure core barrel from the drill string on the Glomar Challenger. *The pressure core barrel was developed by DSDP to sample gas hydrates at high pressures from deep-sea sediments.*

Also this year Deep Sea Drilling Project (DSDP) engineers successfully tested a new coring system. This unique wireline retrievable Pressure Core Barrel (PCB) permits the recovery of deep ocean cores, while at the same time retaining the natural pressures of up to 5000 psi associated with depths. This is of particular significance in the recovery of methane hydrates (clathrates), which have been theorized to exist in deep ocean sediment because of the high pressure and low temperature. In normal coring these hydrates would disintegrate as the cores are brought up on deck, because the pressure is released. However, with the PCB they can be brought intact to the ship, where the hydrates can be studied.

DSDP scientists aboard *Glomar Challenger* traveled 20,000 nautical miles and recovered 8000 m of core from below the ocean floor. Scientists from eight U.S. and five foreign institutions shared the duties of cochief scientist during the various legs of the study.

During DSDP Leg 74 researchers drilled a series of five closely spaced sites down the flank of the Walvis Ridge. The age of the crust at the Walvis Ridge crest, where drilled, is about 70 million years, becoming younger downslope to the west. This age pattern agrees with that indicated by magnetic lineations of the crust, and suggests that the Walvis Ridge first formed at the mid-Atlantic spreading center as an anomalously shallow or above-sea-level area, during the early opening of the South Atlantic that began some 110 million years ago. Benthic fossils indicate that the ridge has sunk since the final outpourings of lava about 70 million years ago. At the shallowest site drilled (1054 m), near the crest of the ridge, beach sands indicate the presence of a large island. This island did not sink below sea level for some 15 million years after its formation.

Scientists on leg 75 learned that the organic-rich black sediments off the coast of Africa were thin layers in strata that are otherwise almost devoid of organic matter. If the ancient Atlantic Ocean did become stagnant, as scientists have speculated, it was only for very brief periods.

Shipboard scientists found that the upwelling of deep ocean water associated with the Benguela Current has left its mark on sediments over a wide area of the southern Angola Basin and

on the eastern Walvis Ridge. The upwelling water is cold, but brings nutrients to the surface and causes blooms of plankton and other marine life. The sediments presently accumulating under the upwelling waters are even richer in organic matter than those formed in the ancient Atlantic. The cores show that the upwelling system has existed for about 6 million years, but was best developed 2 million years ago. A special set of sediment cores formed beneath the upwelling water was frozen so that it can be shared with scientists studying the origins of petroleum.

Among the leg 77 discoveries were samples of an ancient rifted crust beneath the Gulf of Mexico, evidence for drowned carbonate platforms and thick talus deposits, and great thicknesses of limestone with potential oil source beds deposited between 130 and 100 m.y. ago.

Scientists aboard this cruise set out to test a model of the origin and evolution of the Gulf of Mexico that was recently developed from extensive geological and geophysical studies in the area. With this model scientists postulate that the North Atlantic and the central gulf originated in much the same way and at about the same time through breakups of continents and sea-floor spreading 180 to 200 m.y. ago. After a phase of continental rifting (about 150 m.y. ago) young ocean floor began to appear in the rifts, and the continental blocks drifted apart. Soon afterward, the two ocean basins parted company. The Atlantic continued to expand rapidly while sea-floor spreading in the central Gulf of Mexico ceased. The rifted margins of the basins continued to subside, however, as the crust cooled and was loaded with sediment.

Drilling on leg 77 confirmed that the southeastern gulf is underlain by a continental crust that has been rifted and intruded by oceanic magma; that a shallow sea had invaded the newly formed basin; and that a deep sea developed as the ocean crust cooled and subsided. However, the model has had to be modified in other points. For example, small blocks of crust formed during the initial breakup of the continent and continued to move as individual blocks long after deep-sea conditions had been established. Simultaneously, carbonate reefs and platforms on the basin margin rose 1500 m above the ocean floor. The steep flanks were footed by accumulations of reef talus that were recovered in cores and closely resemble the rocks in the oil-bearing Poza-Rica and Reforma trends in Mexico. A thick section of deep-water limestone was deposited seaward of the platforms. Certain types of these limestones were found to be rich but immature source rocks for hydrocarbons. Asphalt-filled fractures with a halo of oil stains recovered at one site suggested the presence of more mature source beds deeper in the section or downdip of the drill sites.

Researchers on leg 78A in the San Juan, Puerto Rico, area investigated the crustal convergence zone, where the Atlantic Ocean plate dives beneath the Caribbean Sea. *Glomar Challenger* scientists drilled six holes to depths of 450 m in more than 5000 m of water on the Barbados Ridge, east of the Antilles Island arc. One drill hole in the undisturbed Atlantic Ocean sediment demonstrated that crust now entering the convergence zone was formed 78 m.y. ago in the central Atlantic Ocean. During subsequent westward drift the crust accumulated sediment more than 450 m thick. Drilling and associated geophysical studies established that the upper, weaker portion of the Atlantic Ocean sediments are skimmed off and deformed, whereas the lower, stronger part slides undisturbed beneath the jumbled mass. Scientists also discovered that a well-lubricated fault zone separates the deformed and undisturbed masses. A similar although artificial lubrication process has been proposed to release stress gradually along faults in California and thereby prevent disastrous earthquakes.

The highlight of leg 78B was the installation of sophisticated equipment in a hole that scientists aboard *Glomar Challenger* had drilled 500 m into the deep sea floor five years earlier. Because the hole was still open and clean to a depth of 600 m, *Glomar Challenger* remained over the site for 12 days making borehole measurements. In addition to a set of downhole geophysical logging tools, shipboard scientists were able to use a Soviet-built downhole magnetometer together with a susceptibility meter, special temperature recorders, formation water samplers, a borehole televiewer provided by the USGS, and an inflatable packer tool that can seal off the hole for permeability and in situ stress measurements. A new ocean borehole seismic observatory being developed by the Naval Ocean Research Development Activity was tested. The instrument successfully recorded several earthquakes that occurred on the Mid-Atlantic Ridge. This success demonstrates the feasibility of emplacing large, unmanned observatories in boreholes anywhere in the ocean floor.

Scientists on leg 79 confirmed the existence of a vast field of salt domes in the deep sea floor off the Atlantic coast of Morocco. The shipboard scientific party deduced that these great masses of salt were probably formed by evaporation in a shallow sea during the earliest stages of the opening of the Atlantic Ocean, a little before Africa began drifting away from North America.

Cores recovered during leg 79 contained granitic rock characteristic of the crust beneath the continent, thus establishing that the deeply foundered western edge of the African continent extends seaward at least as far as the eastern edge of the salt field, and perhaps into the field. The evidence obtained during leg 79 tends to confirm the fit of the Moroccan Margin against the margin of Nova Scotia, where similar salt domes are believed to lie at the foot of the continental slope. The coring also brought back samples of Jurassic limestone 140 to 150 m.y. old, some deposited in quite shallow water where corals and algae flourished, some in deeper water where lime ooze accumulated. The exact dating of these limestone beds and their associated clay layers will help establish the early history of the opening of the Atlantic, when truly oceanic conditions were established.

Scripps manages the Deep Sea Drilling Project, which is funded by the National Science Foundation through a contract with the University of California. The activities of the program are planned on behalf of the scientific community by JOIDES (Joint Oceanographic Institutions for Deep Earth Sampling). UC subcontracts with Global Marine Inc. for drilling and coring using GMI's R/V *Glomar Challenger*. Dr. Melvin N. A. Peterson is project manager, and Dr. Yves Lancelot is chief scientist.

Geological Research Division

Scientists in the Geological Research Division continued their investigations into a number of diverse geologic problems. This year's studies have taken researchers from the depths of the oceans to a mountain in Zaire. Studies include the evolution of the earth's crust and the evolution and biogeography of phytoplankton remains.

A series of studies focusing on several anomalous regions of intraplate seismicity in the South Central Pacific Ocean was completed by Dr. Thomas H. Jordan and graduate student Keith A. Sverdrup. They used information obtained during an earlier shipboard survey in conjunction with seismic observations at distant recording stations to develop a model that attributes the seismicity to "creaking" of the oceanic crust in response to compression by plate-driving forces. In the course of this work they developed new algorithms for locating clusters of seismic events that are already being applied in land-based studies of earthquakes. Dr. Jordan and graduate student James D. Means are using deep-focus earthquakes to study the seismic velocity structure of the lithospheric plates descending into the mantle in subduction zones. Their work indicates that these plates remain coherent to depths much below the deepest earthquakes (which occur at a depth of about 650 km) and thus provides direct evidence for convective interchange of material across the 670-km discontinuity, a hypothesis that is the subject of much controversy.

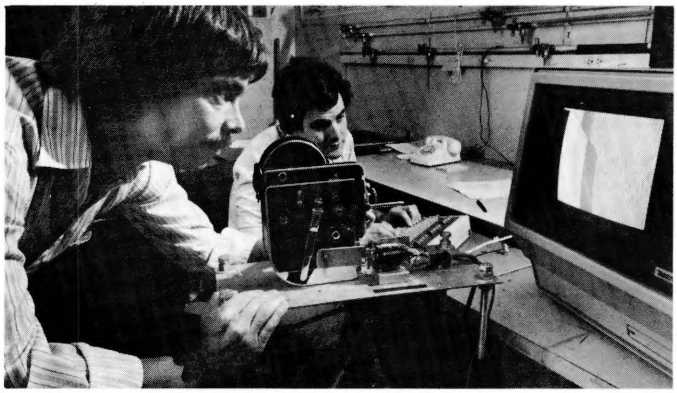
Dr. Randall S. Jacobson completed an intensive study of the structure sediment underlying the Bay of Bengal, and found that the average sound velocity in the sediment increased linearly with depth, but that there is a peak in sound absorption at a depth of 600 m. This is thought to correspond to the depth at which the sediment changes from being mostly liquid to being mostly solid.

Dr. LeRoy M. Dorman, along with Dr. L. Dale Bibee, Oregon State University, Corvallis, initiated a major seismic study of the western Philippine Sea. This area is characterized by deeper water than "normal" for its age and by seemingly low sound absorption. Graduate student Giovanni B. Marchisio aided in this field work, which included long (400 km) and short (50 km) seismic refraction profiles, the latter being executed at various azimuths to measure anisotropy. In addition to the active source work, scientists left instruments for 30 days to record earthquakes from the source regions that surround the western Philippine Sea. This experiment included the first completely successful performance of the new Ocean Bottom Seismometers, developed by Dr. Robert D. Moore. These instruments, the sea-floor counterparts of high quality, 3-component, digital land stations, are valuable aids in understanding the processes that shape the earth's surface. Graduate student Kenneth C. Creager and Dr. Dorman developed a computational technique using satellite fixes and underwater acoustic ranging to accurately fix the locations of multiple sea-floor instruments.

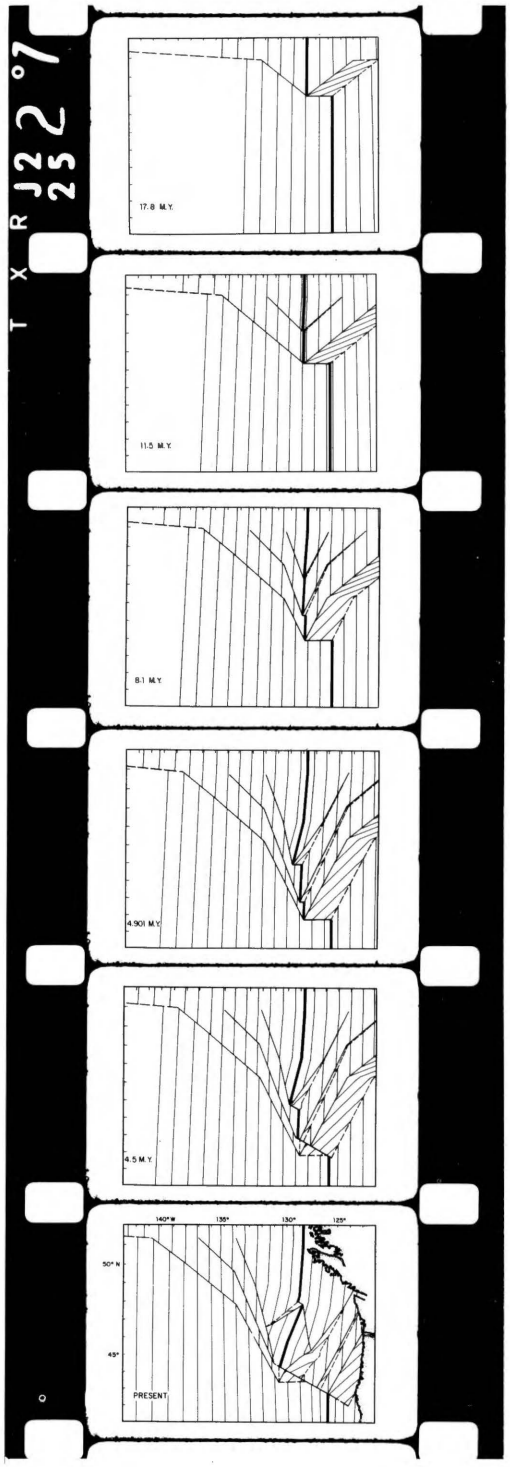
Dr. Joseph R. Curray's group conducted geophysical work south of Java during leg 5 of Rama Expedition aboard R/V *Thomas Washington*. Graduate student Naomi Benaron is presently working on seismic refraction data to understand deep structure of the forearc region. On leg 6 of Rama Expedition, Drs. Gregory F. Moore, George G. Shor, Jr., and Curray, along with Dr. Daniel E. Karig, Cornell University, New York, directed geophysical and geological studies of the forearc region west of Sumatra. Graduate student Desiree Beaudry is currently working on seismic reflection data to understand the sedimentary evolution of the forearc basin. In order to learn more about the deep structure of the forearc region, graduate student Char-Shine Liu is studying expanding spread and constant offset seismic data. Drs. Moore and Karig are currently working on seismic reflection and piston core data from the lower trench slope.

A long-term examination of ocean basin tectonics was continued by Dr. Robert L. Fisher. This year he studied the southwestern Indian Ocean-Antarctica/Africa plate boundary development and crustal composition. A topographic-structural interpretation of 41,200,000 km^2 of Southern Hemisphere Indian Ocean sea floor was completed. Study of the mineralogy and minor element geochemistry of deep crustal and upper mantle peridotites from chasms in the 12,500-km-long Antarctica/Africa-Africa/India plate boundaries was initiated in collaboration with scientists from Woods Hole Oceanographic Institution. This work aims to refine geochemical criteria for distinguishing abyssal and alpine-type peridotites, both of which occur in ophiolite assemblages now on land, and to identify provincial differences in upper mantle sources along the actively spreading ridge systems. Field work was limited to a 33-day trench hadal biology cruise on which rock sampling was a tertiary program; igneous rocks were dredged for the first time from the deep flanks of the Philippine Trench off Mindanao, and nine more hauls were made in and near Challenger Deep, southern Mariana Trench, to complete the section begun there in 1975.

Dr. Richard N. Hey continues his work on magnetic anomalies, propagating rifts, and plate tectonics. His propagating rift model explains spreading center jumps and a large class of sea-floor lineaments oblique to both relative and absolute plate motion that have previously resisted explanation in terms of rigid-plate tectonics. Dr. Hey and a colleague have developed a new computer graphic technique to reconstruct plate tectonic evolution and to make movies linking sequences of plate reconstructions at small successive time increments.



Dr. Richard N. Hey (left) and Mike Keeler (right) film a computer reconstruction of plate tectonic evolution of the Northeast Pacific.



A film sequence of a computer-produced reconstruction of plate tectonic and propagating rift evolution of the Juan de Fuca area in the Northeast Pacific from 17.8 million years ago to present.

Dr. Hey and his associates used this new technique to reconstruct the tectonic evolution of the Juan de Fuca area in the Northeast Pacific, where magnetic stripes on the sea floor were first discovered in terms of two rigid plates and four propagating rifts. The oblique offsets first recognized in the Raff-Mason anomalies result from rift propagation rather than faulting.

In addition to his propagating-rift research, Dr. Hey has found evidence in the fine-scale structure of magnetic anomalies over spreading centers for a short magnetic-field reversal within the Brunhes normal epoch 500,000 years ago, and for a two-layer magnetic source.

The MANOP Bottom Lander, a free-vehicle instrument designed to carry out in situ studies of chemical and biological processes at the sediment-water interface and the relationship of these processes to the formation of ferromanganese nodules, has successfully completed its first free-vehicle deep water deployment in the California borderland. This work, under the direction of Dr. Ray F. Weiss, represents a central part of the Manganese Nodule Program (MANOP). The Bottom Lander is designed to operate as a remote station on the sea floor at depths up to 6 km and for periods as long as one year, carrying out chemical and isotopic tracer experiments and collecting samples of seawater, sediment, and nodules.

Scientists in Dr. Weiss's laboratory have also continued their research on the oceanic and atmospheric distributions of the environmentally important trace gases nitrous oxide, carbon dioxide, and methane. Continuous measurements of these gases in marine air and in surface water were carried out as part of the current TTO (Transient Tracers in the Ocean) study of the geochemistry and oceanography of the North Atlantic. Through this research, scientists will assess the influence of the region's air-sea exchange on atmospheric trace gas distributions and on the composition of nascent North Atlantic deep and intermediate waters. Development of high-precision gas chromatographic techniques has continued, with special emphasis on atmospheric and oceanic studies of the global carbon cycle.

The investigations of Dr. Edward D. Goldberg and associates on the entry of pollutants into the marine environment have furthered the understanding of natural processes in the oceans.

The widespread use of the metal tin in plastics, biocides, and plating has dramatically increased the levels of tin in coastal sediments. For example, high butyl-tin levels are measured in deposits off the California coast, coming from the compound's use in antifouling paints on ships. This compound is not produced naturally. On the other hand, investigations of sediments and algae revealed the ubiquitous presence of naturally occurring organic tins including tin tetramethyl, which sometimes exists in macroalgae. The mode of formation of this most unusual compound has not been ascertained.

The transuranic elements, americium and plutonium, have entered the oceans primarily as a consequence of nuclear weapons testing. The two intensive testing periods were the early 1950s, dominated by the U.S., and the early 1960s, dominated by the U.S.S.R. Each series of detonations ejected into the environment unique isotopic compositions of plutonium, which can be used to define the time of their accumulation in sediments. Scientists have developed this record from Antarctic and Arctic glaciers. Thus, the introduction of plutonium isotopes into the ocean environment can be characterized at their time of entry.

The study of fluxes of these transuranic elements to two adjacent southern California borderland basin sediments, San Clemente and Santa Barbara (less than 100 km apart), differed by more than a factor of six, and plutonium isotopes from the early U.S. tests were clearly evident in recent strata. The two deposits also differed in their chemistries. The Santa Barbara deposits were anoxic, and there is very little evidence of the mobilization of sediments to the overlying waters by organisms. The San Clemente deposits, on the other hand, were oxidizing, and there is ample evidence of bioturbation and the resultant mobilization of materials into the overlying waters. This work has led to the hypothesis that particles constantly move from oxic sediments to anoxic sediments following remobilization of the solid particles by burrowing organisms and transport by currents. The fine particles are more readily resuspended, and such particles can be carriers of sorbed plutonium and americium. The remobilization concept clearly applies to naturally deposited materials and can explain the unusually high accumulation rates in anoxic areas.

Investigations were carried out during the Indian Ocean GEOSECS to characterize the suspended particulate matter, based on the studies of concentrations of particulate Al, Ca, Fe, Cr, Ni, Cu, Sr, and ^{234}Th in surface waters, and of ^{210}PB, ^{230}Th, and ^{234}Th in two vertical profiles (385-4400 m). These studies were conducted by Dr. Devendra Lal and others.

The "ash" (noncombustible phase) concentrations in surface waters closely follow the primary productivity pattern, with higher abundances in samples south of 40°S and lower concentrations in the equatorial and subtropical regions. Opaline silica and $CaCO_3$ are the dominant components of the ash in samples from >40°S and from 7°N-39°S respectively. Aluminosilicates are only a minor constituent of the surface particulate matter. The metal/Al ratios in the surface particles are significantly higher compared to their corresponding crustal ratios for all the metals analyzed in this work. Comparison of enrichment factors between marine aerosols, plankton, and surface oceanic particles seems to indicate that this high metal/Al ratio in surface particles arises from their involvement in marine biochemical cycles. Particulate ^{234}Th activity in surface water parallels the ash abundance, implying that its scavenging efficiency from surface waters depends on the particulate concentration.

The particulate ^{230}Th and ^{210}Pb concentration profiles increase monotonously with depth. The logical mechanism for this appears to be the in situ vertical scavenging of ^{230}Th and ^{210}Pb from the water column by settling particles. The mean settling velocities of particles calculated from the particulate ^{230}Th data using a one-dimensional settling model is about 2×10^{-3} cm/sec. The settling velocity computed from the particulate ^{230}Th profiles does not appear compatible with the particulate ^{210}Pb depth profiles; one possible explanation of the disparity would be that ^{230}Th and ^{210}Pb are scavenged by different size populations of particles.

On the whole, particulate matter's geographic distribution and composition and settling velocities in the Atlantic, Pacific, and Indian oceans are similar, indicating control by similar processes in the marine hydrosphere.

The measured particle settling velocity of $\sim 2 \times 10^{-3}$ cm/sec is about an order of magnitude larger than that expected for the Stokes velocity of particles of 1 μm size. Scavenging processes in the ocean are expected to be controlled by these particles. This is a puzzle that may be explained by large particles carrying along smaller particles during their downward transport. The expected rate of collisions of particles of 1 μm size with larger particles is adequate to explain the measured particle sinking rate. Thus the smaller particles in the oceans appear to be transported downwards by the larger particles by a piggyback mechanism.

Several new projects have been initiated, and earlier work continued, in the new isotope geology and geochronology laboratory operated by Drs. Günter W. Lugmair, J. Douglas Macdougall, and associates. This facility uses radiogenic isotopes to understand the history and evolution of the earth's crust and mantle. Thus most of the current work is focused on the strontium and neodymium isotopic composition of volcanic rocks from a variety of tectonic settings. These studies began with Dr. Richard W. Carlson's intensive investigation of the Columbia Plateau flood basalts in the northwestern United States, which clearly delineated the interaction between a depleted

upper mantle source and old crustal material. A second important flood basalt province—the Deccan Plateau of India, which occupies a different tectonic setting—is also being studied. Graduate student John J. Mahoney and Dr. Macdougall, along with Indian collaborators, made preliminary collections of basalts from the western part of this province. The initial chemical and isotopic results for these samples show some similarities to the Columbia Plateau results in terms of the mantle source characteristics and crustal influence, but also appear to be somewhat less straightforward.

A completely different eruptive style characterizes the rare eruptive rocks that occur in a region of thick crust along the suture zone between the Indian and Asian plates in southwestern China. Drs. Lugmair and Macdougall visited the People's Republic of China to initiate a collaborative study of these rocks. Their visit included field work in Yunnan Province, near the Burma border, and yielded a diverse suite of volcanic rocks for analysis. The principal Chinese collaborators in this project are spending approximately a year at Scripps working on these samples. Initial results appear to indicate little or no mantle "signature" in the isotopic composition of these rocks, but clearly show the influence of several distinct crustal reservoirs.

In addition to the various continental eruptives discussed above, studies of oceanic basalts also play an important role in understanding the upper mantle. A major effort has been made to examine the fine-scale isotopic and chemical features of ridge basalts from the moderately fast spreading ridge segment at 21°N on the East Pacific Rise. Basalts from this region show the first evidence for small-scale isotopic heterogeneity among ridge basalts, and are providing insights into the chemical nature of the underlying mantle sources.

In separate but somewhat related projects, recent mantle and magma chamber processes are being investigated by graduate student Sally Newman, Dr. Robert C. Finkel, and Dr. Macdougall using thorium and uranium isotopes. Combined with the Sr and Nd isotope work mentioned above, these studies have documented recent extensive Th/U fractionation in the 21°N East Pacific Rise samples. Similar work on the volcanic rocks of the Cascades—including Mount St. Helens—is providing information about the timing of eruption and chemical processes in the source regions of these volcanoes.

Dr. Macdougall is also researching the evolution of the primitive carbonaceous chondrites. This work is directed primarily at the chemical and isotopic features of the early condensed refractory inclusions in these meteorites, and it involves collaborators from four other institutions.

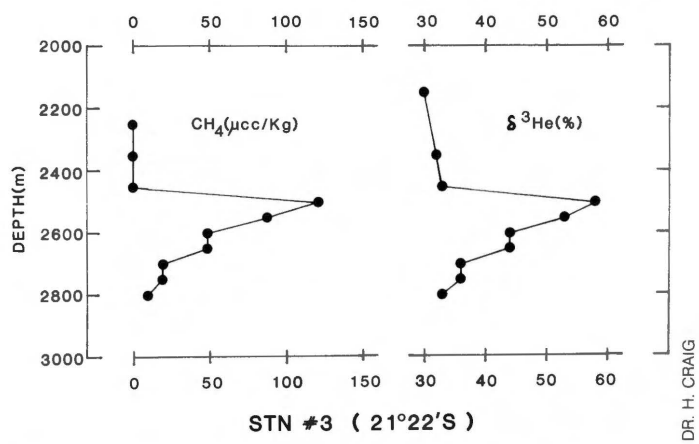
Within the general framework of the early chronology and geochemical evolution of the moon, Drs. Lugmair and Carlson measured several ancient lunar crustal samples using the Sm-Nd dating technique. They found that, although the crystallization ages may vary between 4.2 and 4.35 billion years (b.y.), the chemical characteristics of their source materials were established as early as ~4.35 b.y. ago. Isotopic studies on titanium extracted from "refractory" inclusions from the Allende meteorite showed that isotopically anomalous Ti is ubiquitous in this material and predates the solar system, carrying the signature of the processes that produce this and presumably other elements within supernovae.

A detailed seismic experiment in the vicinity of the hydrothermal vents on the East Pacific Rise at 21°N was conducted by Dr. John A. Orcutt and associates. They determined that earthquakes there were shallower than 2 km, immediately above the magma chamber that ultimately supplies the material forming the ocean basins. Harmonic tremors akin to those observed prior to the eruptions of Mount St. Helens and volcanoes in Hawaii were also recorded.

Dr. Orcutt is studying quantitative seismology to determine the structure of the earth's crust and upper mantle. Dr. Orcutt and a Canadian scientist developed a technique for directly determining the structure of the earth's crust using the data recorded by seismometers in refraction and reflection profiles. Graduate student Marilee Henry and Dr. Orcutt have formulated a special stacking procedure for compacting extensive seismic data sets for subsequent interpretation. A technique for the direct inversion of this stacked data into an earth model that allows an objective assessment of the errors in the derived model has been developed by graduate student Peter R. Shaw. Another technique was developed by Dr. Orcutt and graduate student Richard G. Adair for studying seismic wave propagation in the vicinity of the sea floor. They also studied the strong motion effects of earthquakes located in the oceanic crust. Working with graduate student Kevin R. MacKenzie, Dr. Orcutt has interpreted seismic data from oceanic plateaus in the Indian and Pacific oceans and found them to be akin to neither oceanic nor continental crust.

Dr. Harmon Craig and associates in the Isotope Laboratory continued their studies of mantle volatile emanations on land and at sea. Dr. Craig and Valerie Craig returned to Djibouti to continue the previous year's studies in the Afar Depression. Later the Craigs, along with Dr. William Rison and graduate student Robert J. Poreda, continued the laboratory's East African Rift Valley survey, with volcanic and geothermal studies in Kenya, extending from Lake Turkana at the Ethiopian border to Lake Magadi at the Tanzanian border. Finally, a survey in the Western Rift in Rwanda and Zaire was carried out, with collection of deep water samples on Lake Kivu and geothermal sampling north of the lake. Dr. Rison and Poreda also climbed Mt. Nyiragongo in the Virunga Range to collect volcanic gases near the summit—gases which (as it turned out) contained a very large ^{3}He-rich mantle component.

In the spring Dr. Craig, Valerie Craig, and graduate student Kyung-Ryul Kim participated in leg 8 of Vulcan Expedition, surveying the East Pacific Rise at 20°S for new hydrothermal vent fields. Dr. Craig and Dr. Robert D. Ballard, Woods Hole Oceanographic Institution (WHOI), were cochief scientists on this expedition, in which deep-water methane "sniffing" aboard R/V *Melville* was used (for the first time) in conjunction with WHOI's ANGUS deep-sea camera system to search for hydrothermal emanations. Kim's shipboard measurements of methane showed the existence of deep methane plumes that matched precisely the ^{3}He plumes later measured on these samples in the laboratory. Thus, the gas chromatographic technique for shipboard methane surveying provides the first



East Pacific Rise ridge-crest profiles of dissolved methane and ^{3}He/^{4}He anomaly in dissolved helium on the southern section of the rise, found by graduate student Kyung-Ryul Kim and Dr. Harmon Craig on Vulcan Expedition Leg 8. Methane units are 10^{-6} cc (STP)/kg of water. δ (^{3}He) is the percentage enrichment of the ^{3}He/^{4}He ratio relative to atmospheric helium. The concordance of methane with the injected primordial ^{3}He from the mantle establishes this as the first deep-ocean profile of "abiogenic" methane. Two new hydrothermal vent areas were found by cochief scientists Dr. Craig and Dr. Robert D. Ballard, WHOI, in the vicinity of 20°S during this expedition.

real-time method for tracking hydrothermal vent emanations at sea.

In other work in the Isotope Laboratory, Dr. John A. Welhan completed his study on the geochemistry of geothermal gases of three areas: the 20°N hydrothermal vents on the East Pacific Rise, the Salton Sea geothermal area in California, and Yellowstone National Park. Drs. Chun-chao Chou and Craig continued the study of polar ice cores. A new cold room, operating at −20°C, has been installed for storing and sampling the cores. As part of this work, a study of the atmospheric gases in hailstones showed they consist of two components—a solubility component of gases originally dissolved in liquid water, and a trapped air component occluded in the ice. Dr. Shi Huixin and Mu Songlin, State Seismological Bureau, Beijing, People's Republic of China, were visitors in the laboratory as part of an exchange following last year's work in Tibet by the Craigs.

Dr. Yu-chia Chung's research is in three areas: hydrothermal systems on the East Pacific Rise (EPR)—studies of radioisotopes in hydrothermal precipitates and fluids; earthquake prediction studies in southern California; and the Geochemical Ocean Sections Study (GEOSECS).

Initial studies of radioisotopes in sulfide precipitates from the EPR hydrothermal systems suggest that the cycle of buildup and decay of the sulfide chimneys is on the order of tens to hundreds of years. Studies of the hydrothermal systems are continuing, and more systematic measurements of the uranium and thorium series isotopes in the hydrothermal fluids and precipitates are under way. Earthquake prediction studies based on geochemical monitoring of groundwater properties continued. Measurements of GEOSECS Indian Ocean ^{210}Pb and ^{226}Ra samples have been completed; interpretation and modeling of the data are in progress.

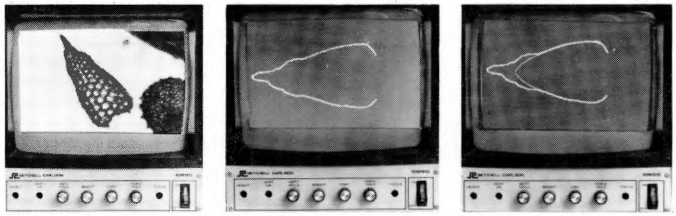
Dr. Hans R. Thierstein completed a study of the evolution and biogeography of late Cretaceous and earliest Tertiary calcareous phytoplankton remains. He could demonstrate that the terminal Cretaceous plankton extinction event was of catastrophic intensity and affected oceanic surface waters more strongly than any other environment, a fact that is difficult to reconcile with recently proposed models of impacting extraterrestrial objects. Graduate students and Dr. Thierstein have made progress in development of a new chronostratigraphic technique, the results of which are expected to greatly enhance the ability to reconstruct and understand paleoceanographic processes in the Mesozoic.

Dr. William R. Riedel and Alexis A. Budai are developing computer techniques to handle greater amounts of information on microfossils more objectively than has been possible with conventional methods. A microcomputer system is used to store fossil images and associated alphanumeric information. The researchers are also beginning to automatically evaluate the image shapes in mathematical terms. Annika Sanfilippo and M. Jean Westberg continue to investigate the stratigraphy and paleoenvironmental significance of Cenozoic and Mesozoic radiolarian assemblages. They have described the effects of the late Miocene desiccation of the Mediterranean on the radiolarian assemblage there.

Patricia S. Doyle and Michael D. Gottfried are improving the stratigraphic resolution attainable by using the microscopic teeth and scales of fishes in deep-sea clays, by describing additional forms, and determining their occurrence in samples dated by other means.

Marine Biology Research Division

Investigations in the Marine Biology Research Division embrace experimental and descriptive biological disciplines, including physiology, biochemistry, microbiology, developmental and systematic biology, and ecology of the sea. Many of the studies are comparative, and structures, events, or processes are examined in a wide range of marine and terrestrial organisms. An objective is to gain new insight into fundamental problems of biology and medicine by better understanding marine organisms and the manner in which they adapt to life in the sea.



Computer-automated evaluation of fossil image shapes is shown above. Alexis A. Budai is at work at the computer. On the two screens is the pore pattern arrangement (TV image on right; digitized image on left). Above is the nonparametric curve-fitting to outline shape (from left is the digitized image, outline, and fitted curve).

Algae in nutrient-depleted waters absorb arsenate in their quest for phosphate. They avoid arsenic poisoning by methylating it to produce nontoxic trimethylarsoniumlactate derivatives in which arsenic displaces nitrogen of analogous metabolites. In research on Australia's Great Barrier Reef, Dr. Andrew A. Benson discovered arsenic accumulation to the extent of 0.2 percent in the kidneys of giant clams. His recent studies have revealed that this arsenic is in the nontoxic compounds produced by symbiotic algae harbored by *Tridacna*. The *Tridacna* use a remarkable mechanism for excreting arsenic that appears widespread in marine organisms. The animal converts the arsenicals to a variety of gill membrane lipids. Exposed to the sea, the arsenic is rapidly lost by oxidative processes on the gill surfaces. Similar processes in algae have been revealed through the work of Robert V. Cooney and the late Juan Herrera-Lasso in Dr. Benson's laboratory.

Dr. Ted E. DeLaca is studying the physiology and ecology of benthic foraminifera. His investigations include the uptake and metabolism of microorganisms (such as bacteria and diatoms) and dissolved organic substances; respiratory rates; the significance of predation on their populations; and functional morphology. Study localities include tropical, temperate, and polar environments. A principal study locality is the shallow-water benthos of McMurdo Sound, Antarctica. Currently Dr. DeLaca is examining the metabolism and population dynamics of several foraminiferal species, and the chemical and biological composition of interstitial water in the sediments.

In his study of seawater samples obtained off the southern California coast, Dr. Theodore Enns found no appreciable catalysis of CO_2 to bicarbonate conversion, nor carbonic anhydrase activity. Samples included surface-slick and 1800-m-deep water. It is concluded that equilibration between

atmospheric CO_2 and seawater is very slow and probably incomplete.

Dr. Denis L. Fox continues his work on carbaminoprotein equilibria and entropy exchanges involved in the reversible CO_2-narcosis of living protoplasm.

Of particular interest in Dr. Francis T. Haxo's laboratory are the first successful comparisons of spectral assimilation and absorption curves in the deep-water marine Cyanobacterium *Synechococcus*. This bright red, phycoerythrin-rich autotroph was originally isolated into culture from 100-m Sargasso Sea water. As expected, cellular absorption and photosynthetic activity were most pronounced (and effective) in the middle of the visible spectrum (550 nm maximum), with chlorophyll *a* absorption accounting for significant activity at the ends of the spectrum. Blue photons captured by the abundant carotenoids present were quite inefficient in photosynthetic O_2 evolution. This is puzzling in view of the predominately blue character of submarine illumination at the collection depths of this algal isolate.

Among the variety of topics being studied in his laboratory, Dr. Robert R. Hessler devoted time to several aspects of crustaceans. In a review made with George D. Wilson on the biogeography of deep-sea malacostracans, he documented three patterns of distribution that could be related to ecological and historical factors. Another study on the evolution of locomotion revealed that the many methods of movement in advanced forms are specializations of a very different primitive style.

Dr. Nicholas D. Holland has been studying the fine-structure of articulations of crinoid echinoderms. He has discovered a possible mechanism for the motility of the cirri of feather stars. The contractile apparatus is evidently a bundle of 5-nm filaments running within the cytoplasm of the epithelial cells lining the oral and aboral coeloms of the appendage. He has also elucidated the fine structural changes that take place when syzygial articulations of the feather star arm are autotomized. Observations before and after autotomy suggest that the autotomy mechanism may comprise rapid neural transmission from stimulation site to syzygy, triggering a massive exocytosis of granules from presumed neurosecretory axons. The released neurosecretions (which could include chelating agents, strong acids, proteolytic enzymes, or enzyme activators) etch the skeleton and lower the tensile strength of the ligament fibers by weakening the collagen fibrils and the interfibrillar material.

Dr. Ralph A. Lewin continues to investigate an enigmatic marine alga *Prochloron,* which usually lives in symbiosis with didemnid ascidians in tropical reef areas. Large numbers of infected colonies were recently found at low-tide levels near Puerto Peñasco, Mexico. With Dr. Charles Birkeland, University of Guam, and Dr. Lanna Cheng, he studied autonomous movements of the host colonies, which presumably help to orient them for the benefit of their photosynthetic symbionts. Dr. Lewin and colleagues demonstrated that the algae produce water-soluble products that may help nourish the host animals. Bo Tang Wu, Guangzhou, People's Republic of China, has been working on the diatom *Phaeodactylum,* trying to obtain UV-induced mutant strains that might be higher in lipid content than the usual wild type.

Scientists in the laboratory of Dr. Kenneth H. Nealson are working in several areas of marine microbiology, including biogeochemistry, the genetics of marine bacteria, and bioluminescence. The highlight of bioluminescence research this year was the construction and deployment of an offshore station, located over Scripps Canyon, for the continuous monitoring of light emission and optical properties of the ocean. Data gathered from this station are relayed to a computer at the end of the Scripps Pier, analyzed, and then made available on a real-time basis for further study and manipulation. Dr. Jon A. Warner will use these data to study spectral and kinetic properties of organisms in situ, and to determine the location and migration of luminous organisms on both short and long time scales.

Work in Dr. William A. Newman's laboratory progressed along several fronts. The most exciting breakthrough was graduate student Stephen C. Piper's discovery that a local intertidal chiton known as *Nuttallina fluxa* actually consists of two species. He had found behavioral, physiological, and morphometric differences between high and low individuals along the shore, which led him to suspect that he might not be dealing with a single population. He used gel electrophoresis to prove his theory. Graduate student Michael E. Huber is working on crab symbionts of corals, testing a sympatric speciation hypothesis on which assortative mating serves as the isolating mechanism. A new array of primitive crustacean symbionts of deep-sea gorgonians has been discovered by graduate student Mark J. Grygier. Drs. Newman and Frederick R. Schram are completing a monograph of the Eocene barnacles of Tonga.

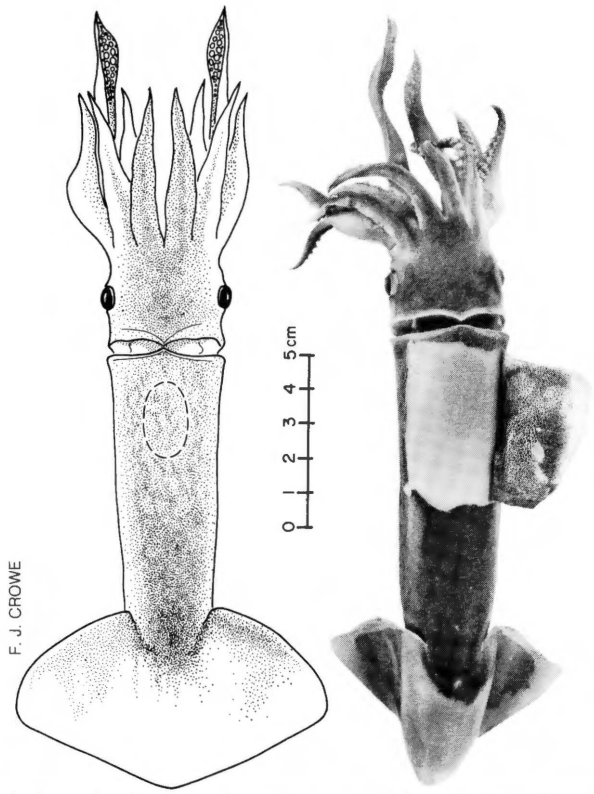
Studies of the ecological energetics of the deep-sea benthic boundary layer in Catalina Basin continue in Dr. Kenneth L. Smith's laboratory. So far they have resulted in insights into the functioning of this community as a component of the open ocean ecosystem. Metabolic rates of mixed macrozooplankton measured in situ at four discrete depths to 50 m above the sediment-water interface significantly decreased with increased distance above the bottom. These rates of the macrozooplankton are insignificant when compared to the metabolic rates of the benthic boundary-layer bacterioplankton and sediment community measured at the same time in the same area. Other components of the benthic boundary-layer community are currently under study in the Catalina Basin, off Southern California, with the ultimate goal of constructing a carbon, nitrogen, and energy budget for this community of the open ocean ecosystem, an active site of remineralization.

A variety of studies focusing on the common theme of biochemical adaptation to the marine environment were conducted in the laboratory of Dr. George N. Somero. Work involved Dr. Michael A. Castellini's study of enzymic and buffering ability contributions to diving in seals and high-speed swimming in fishes. The interactions of urea, methylamines, pH, and temperature in controlling enzyme subunit assembly and metabolic rates were investigated by Dr. Steven C. Hand. Dr. Horst K. Felbeck is continuing studies on sulfide-driven carbon reduction in tube worms and clams from sulfide-rich habitats such as the deep-sea hydrothermal vents.

Other investigations in Dr. Somero's laboratory include molecular adaptations of latitudinal populations of sea anemones, and the polymerization thermodynamics of muscle actins from animals adapted to different temperatures and pressures. Study continues on the enzyme patterns in muscle and brain of fishes living at different depths and having different locomotory and feeding habits, and on the structural correlations of enzymic adaptation to different temperatures.

In a continuing study of the algal turf that covers portions of intertidal rocky habitats in San Diego County, California, Dr. Joan G. Stewart documented cyclical fluctuations in the amount of trapped sand and investigated the effects of sand movement and burial on individual algal species. Morphological characteristics shared by several taxa abundant in this vegetation include secondary attachment structures and creeping growth. A laboratory investigation of the perennial alga *Pterocladia capillacea* has shown a potential for regenerative vegetative growth throughout the year, with quantitative differences in the response related to day length and temperature.

Dr. Frederick I. Tsuji, in collaboration with Gary B. Leisman, discovered a new type of bioluminescence system in the oceanic squid *Symplectoteuthis oualaniensis*. It is found that in *Symplectoteuthis* the essential light-emitting components are membrane-bound, and light emission is triggered by either potassium or sodium ions. Such a system has not been ob-



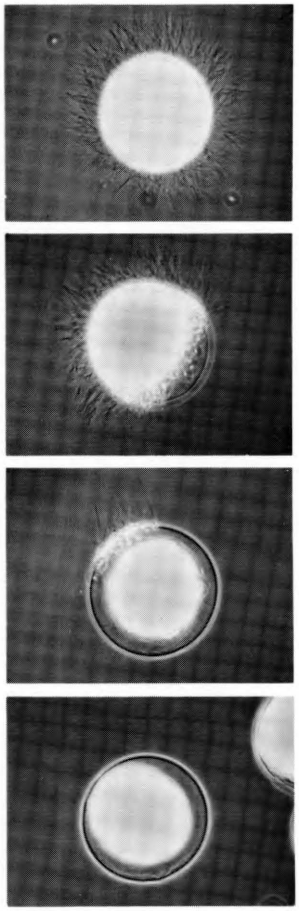
Dorsal view of a luminescent pelagic squid from Hawaii, Symplectoteuthis oualaniensis. *In the drawing on the left the dashed circle is the location of the luminous organ. The photo of the specimen on the right shows that the light organ is slightly darker than the surrounding white muscle tissue.*

served in other bioluminescent organisms. Biochemical studies are presently under way to purify and further characterize the system. The enzyme responsible for catalyzing the bioluminescence reaction in the marine ostracod crustacean *Cypridina hilgendorfii* is now also being purified in order to determine its amino acid sequence. The results should provide a better understanding of the molecular mechanism of the reaction.

Scientists in Dr. Victor D. Vacquier's laboratory are interested in the biochemical mechanisms of the interaction of sperm and eggs in sea urchins and abalones during fertilization. They are attempting to isolate the sperm membrane proteins involved in reception of the egg. The sea urchin sperm cell membrane has been isolated, and three major proteins called 84K, 110K, and 115K identified. There is evidence that 84K may be involved in the triggering mechanism of the sperm acrosome reaction. In a study of the cyclic nucleotide metabolism of abalone sperm, the most interesting finding is that the content of sperm cyclic AMP can be regulated by extracellular calcium. Scientists have purified the enzyme that the abalone sperm uses to digest its way through the egg envelope.

In Dr. Benjamin E. Volcani's group, work contines on the role of silicon in diatom metabolism and cell wall morphogenesis. Dr. Pinakilal Bhattacharyya found that partial purification of a silicate ionophoretic activity from *Nitzschia alba* results in two components. Dr. Robert F. Aline, Jr., characterized two enzymes, adenylate cyclase and guanylate cyclase, from *Cylindrotheca fusiformis.* Graduate student Chia-Wei Li used electron microscopy to determine the sequential development of the multistructural wall of *Ditylum brightwellii* and to study the effects of microtubules poisons on its development. Christopher D. Reeves, a UC San Diego graduate student, has demonstrated that, unlike all other eukaryotes examined so far, *C. fusiformis* does not contain polyadenylate mRNA.

Dr. Claude E. ZoBell has been guiding investigations designed to minimize primary film formation in OTEC pipe lines.



Dr. Victor D. Vacquier injects a sea urchin to induce the release of gametes. At right, sea urchin sperm are shown detaching from the egg surface in the seconds following the fusion of one sperm with the egg. An enzyme (discovered at Scripps) coming out of the fertilizing egg digests the bonds between the supernumerary sperm and the egg surface.

California Space Institute

Activities at the California Space Institute, under the direction of Dr. James R. Arnold, take place on many University of California campuses (all, in fact, except the San Francisco campus). The institute is headquartered on the Scripps campus, and Scripps scientists are participating in two of the statewide projects. The first is Coastwatch, an integrated project for remote sensing of the coastal strip of California and offshore waters. Dr. Raymond C. Smith and his colleagues are doing the oceanographic portion of this study. Dr. Jerome Namias and other members of the Scripps Climate Research Group are participating in a Cal Space statewide project on regional long-range weather forecasts for the Pacific coastal strip. Dr. Richard C. J. Somerville heads the Cal Space Climate Panel and is carrying out climate predictablility research with Cal Space sponsorship. Dr. David R. Criswell is engaged in research on the utilization of the space environment and materials. Drs. Criswell and Arnold have a grant in this field for a project carried on jointly with Rockwell Corporation.

The institute sponsors weekly seminars on various aspects of space technology and remote sensing.

Institute of Geophysics and Planetary Physics

The Institute of Geophysics and Planetary Physics is a University of California systemwide institute with branches on the Davis, Los Angeles, Riverside, and San Diego campuses. The San Diego branch is located at Scripps Institution of Oceanography and is intimately joined to Scripps by a variety of scientific associations.

Scientists with the year-old Crustal Deformation Observatory Project aim to evaluate and improve instrumentation for measuring crustal deformation in a tectonically active area. This reasearch is being conducted at Cecil and Ida Green Piñon Flat Observatory (PFO) with an array of instruments capable of resolving the signals generated by stresses associated with the San Jacinto and San Andreas fault zones. Eleven institutions are involved, utilizing techniques ranging from NASA's project ARIES to Carnegie Institute's deep borehole strain meters. Emphasis has been placed on establishing the coherence between different methods of long base length (500 m) tilt measurements. Research efforts by IGPP personnel include the design and construction of a 535-m fluid tiltmeter by graduate student Frank K. Wyatt.

In a related project, Drs. Jonathan Berger and James N. Brune are deploying a high sample rate digital seismic array on the nearby San Jacinto Fault. Data from the array will be telemetered to IGPP via a microwave link.

Cooperative seismic studies with Mexico, including investigations of seismic hazard, earthquake strong motion, earthquake mechanism, and earth structure, are being continued by Dr. Brune and associates. A special effort is being made using theoretical, numerical, and physical models to understand and estimate the probabilities of large ground accelerations that might damage sensitive structures such as nuclear power plants.

Dr. John G. Anderson and an associate are working on a theoretical study of strong ground motion caused by a kinematic model for faulting during an earthquake.

Dr. Michael S. Reichle continued his cooperative research on northern Baja California seismology with the Centro de Investigación Científica y de Educación Superior de Ensenada, Mexico. He and a graduate student are using teleseismic body and surface waves to determine the source mechanism of the June 9, 1980, Mexicali Valley earthquake.

Richard S. Simons worked on reduction and analysis of strong motion data from the June 9, 1980, Mexicali Valley earthquake. He and Dr. Reichle are using a combination of United States and Mexican data to refine the seismic history of some of the more active parts of northern Baja California.

Dr. Thomas H. Jordan and colleagues have developed new techniques for the seismological study of lateral heterogeneities in the earth's mantle, which should prove useful in elucidating mantle dynamics. He and graduate student Paul G. Silver have shown how small shifts in the frequencies of the earth's free oscillations can be inverted for the three-dimensional variations in seismic velocities and density. A systematic study using IDA (International Deployment of Accelerometers) data has confirmed the existence of substantial heterogeneities in the upper mantle that were indicated by previous studies of body waves and surface waves. Dr. Jordan has extended the theoretical formulation of this inverse problem to include information provided by the amplitudes of the free oscillations.

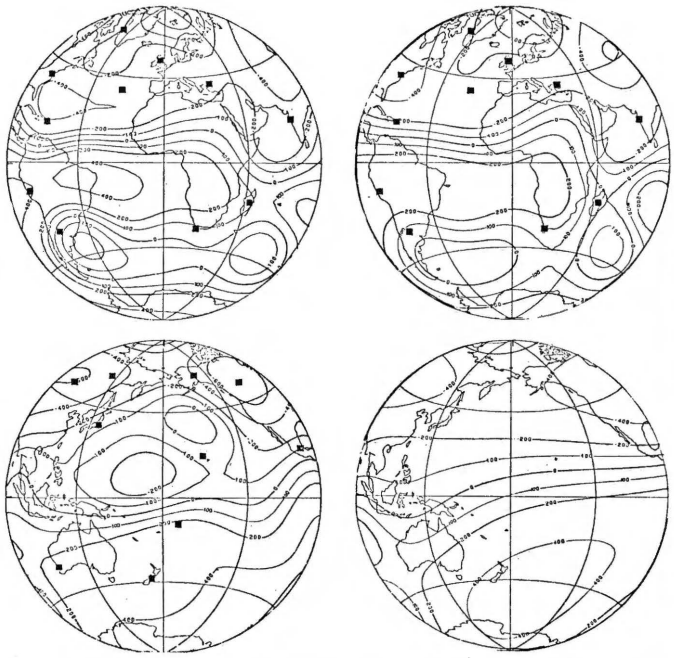
A preliminary study of IDA data by graduate student Mark A. Riedesel, Dr. T. Guy Masters, and Dr. Jordan indicates that the effects of lateral heterogeneity on fundamental-mode amplitudes are considerable, accounting for a root-mean-square fluctuation of 30 percent or more. At frequencies above 5 mH, lateral heterogeneity is best constrained by phase-velocity observations of traveling-wave groups. Dr. Jordan and graduate student Arthur L. Lerner-Lam have developed a new technique for recovering phase-velocity information based on first-order perturbation theory and a Filon quadrature scheme that allows the direct inversion of differential cross spectra obtained by matched filtering observed seismograms with synthetics. This method offers many advantages over classical surface-wave techniques and should permit more accurate recovery of higher-mode information.

Drs. Masters and Gilbert have continued investigating the earth's normal mode spectrum using IDA data. The effect of lateral heterogeneity on complex amplitudes and frequency has received detailed examination: this is important both for retrieval of source mechanisms (moment tensors) and measurement of attentuation factors. Stable methods for retrieving the moment tensor have been developed. Stacking of records using these mechanisms has revealed anomalous (and presently unexplained) splitting of high Q overtones.

Dr. John A. Orcutt and a New Zealand associate completed analysis of seismic data from the Snake River Plain in Idaho. They discovered, deep in the continental crust, a probable magma body that grows in size toward the hydrothermally active Yellowstone National Park area. Dr. Orcutt and graduate student Allen H. Olson have studied another set of seismic data from the Imperial Valley of California and have used it to successfully predict strong ground motion from a realistic earthquake source. With Dr. Brune, they have used the derived Imperial Valley structure to directly determine the fault displacements at great depth during the 1979 Imperial Valley earthquake. Dr. Reichle and Dr. Orcutt have used teleseismic compressional and shear waves to study several large earthquakes along the western coast of Mexico and have developed a theory to determine local fault displacements from earthquakes recorded at ranges in excess of 4000 km.

Dr. George E. Backus, with graduate students David Garbasz and Jeffrey J. Park, has finished the analysis of errors in the Forsythe-Uyeda model of plate-driving forces. They confirmed that slab pull and slab resistance are the main forces, but found that their other conclusions could be noise. Dr. Backus has also worked out the theory of the electric field produced in the mantle by the core dynamo, and has shown that the magnetic field alone cannot even approximately give the core fluid velocity just below the core-mantle boundary layer.

Dr. Backus, Dr. Robert L. Parker, and graduate student Loren Shure have developed a technique for calculating maximally smooth magnetic fields based upon a finite number of observations. This may be applied to the prediction of the magnetic field at the surface of the core, which with traditional methods



INSTITUTE OF GEOPHYSICS AND PLANETARY PHYSICS

The left pair shows a radial magnetic field at the surface of the core that is maximally smooth under a specific norm and satisfies vector data at the 21 surface stations shown by squares. The right pair shows a core field obtained from only 11 of the stations, all in one hemisphere. Note the very smooth field under the Pacific hemisphere. Note also that the Atlantic hemisphere has not been qualitatively changed by the loss of data.

may appear irregular, particularly if the measurements are sparse.

Dr. Parker has continued his work on methods of finding the earth's electrical conductivity profile from measurements of electric and magnetic fields at the surface. He and a visiting student discovered several new techniques using quadratic programing and continued fractions.

Dr. John W. Miles continued his work on nonlinear waves and diffraction theory.

Dr. Walter H. Munk and associates continue their research on ocean acoustic tomography. A demonstration experiment to map mesoscale eddies by this technique is under way in the Atlantic. Nine acoustic moorings and two environmental moorings have been set. For sea truth, there have been three CTD and two AXBT surveys. Researchers are also constructing synthetic records to aid in a more complete analysis of the experimental data, and are using vertical directivity to help identify ray paths. Studies of tidal variability in acoustic transmissions and work on determination of tidal data planes for boundary problems have continued.

Dr. Richard L. Salmon is developing an appropriate form of Hamilton's principle of mechanics to serve as the basis for large-scale models of the ocean thermocline.

Dr. Robert H. Stewart has used radio waves to investigate the dynamics of ocean waves and surface currents. He is project scientist for a new oceanographic satellite (TOPEX) being designed by the Jet Propulsion Laboratory in Pasadena, California. TOPEX will be able to measure ocean surface topography and, thus, surface geostrophic currents with great accuracy.

Dr. Richard A. Haubrich has analyzed long series of sea-level data using the tidal response method to obtain that part of the sea level that is driven by the earth's resonant wobble at a period of 14 months. This low-frequency pole tide is buried in the noise of most sea-level records. Spatial and temporal models are being fitted to the data to discover the physical mechanism of the ocean response.

Dr. Hugh Bradner continues work on aspects of the DUMAND Project (Deep Undersea Muon and Neutrino Detection) such as site studies, pulse generation by high energy charged particles in liquids, bioluminescence, and preparations for measurements of cosmic ray intensity from the ocean surface to 4 km depth.

Project IDA, a global network for the study of long-period seismic phenomena, is under the direction of Drs. Berger, J. Freeman Gilbert, and Duncan C. Agnew. Two new stations were added this year in Japan and the People's Republic of China.

The Cecil and Ida Green Piñon Flat Observatory was officially opened as a part of the University of California. Please refer to the Highlight sections of this report for details.

Institute of Marine Resources

The Institute of Marine Resources (IMR) fosters the enhancement of marine-related research, facilities, public service, and education both within the university and with outside industry and government. IMR operates on a universitywide basis, under the direction of Dr. Fred N. Spiess, and is headquartered at Scripps.

The California Sea Grant College Program, headed by Dr. James J. Sullivan, is administered through IMR and is also based at Scripps. California Sea Grant—largest in the national Sea Grant network—supports research activities in public and private universities and colleges throughout the state. At Scripps more than 20 projects were funded by Sea Grant in 1980-1981. Sea Grant work at Scripps includes the national Nearshore Sediment Transport Study and an extensive international project with Mexico.

IMR directly supports a number of research activities and research units at Scripps; a brief account of the principal ones follows. Reports of the overall Sea Grant and IMR programs are available from their headquarters.

Nearshore Research Group

During the past year the research activities of this group, headed by Dr. Richard J. Seymour, have focused on coastal wave climatology and nearshore sediment transport. The coastal wave network has been increased under the direction of Meredith H. Sessions, with 15 new stations (including one on the Great Lakes and two on the Atlantic coast) and a total of 42 additional measuring instruments. Methods were evolved for analyzing wave data in near real time, and wave parameters are now being transmitted four times each day to the National Weather Service for inclusion in marine weather broadcasts.

David Castel and Dr. Seymour have been conducting research on the coupling between both gravity and infragravity waves on the shelf and the basin oscillations within Mission Bay in San Diego. They also evolved an analytical technique for objectively determining the local shoreline normal direction at the wave directional arrays, which can be calculated spectrally. This enhances the accurate estimation of longshore momentum flux.

Dr. Seymour is investigating incident wave climates and cross-shore transport within the Nearshore Sediment Transport Study (NSTS). Group scientists have developed refraction routines to estimate the wave directional spectra in shallow water, and Dr. Seymour has been involved in the formulation and testing of longshore and cross-shore transport models. All published cross-shore transport models were evaluated against a data set taken at Torrey Pines Beach, Del Mar, California. The prototype of an inexpensive and accurate continuous beach profiling instrument has been developed.

Marine Natural Products Group

This group, guided by Dr. William H. Fenical, has been studying the natural organic compounds produced by marine organisms

as largely defensive adaptations. Whereas the academic interests of this group lie in basic organic chemistry and the biological and ecological facets of marine chemical adaptation, one of their more important goals is the development of benthic marine resources for new pharmaceuticals and agricultural chemicals. Several compounds are being considered for patenting, and a sizable biotesting program has been established within the University of California and with several industries. Dr. Richard R. Izac was instrumental in developing the group's expertise in liquid chromatography and Fourier-transform nuclear magnetic resonance. He was also involved in several major investigations of ichthyotoxins isolated from Pacific soft corals. Dr. William H. Gerwick recently completed an extensive study of the diterpenoids and acetegenins produced by brown algae of the family Dictyotaceae.

Food Chain Research Group

The objective of this group is to better understand the distribution and metabolic activity of marine bacterioplankton, phytoplankton, and zooplankton; to describe the routes and fluxes of organic matter between these trophic levels; and to study the physical/chemical environment as it is related to the distribution and activity of living organisms throughout the oceans. The Food Chain Research Group (FCRG) emphasizes laboratory experimentation and the development of techniques and methods for solving biological problems in the sea. The intermeshing of laboratory work and field studies is evident by the participation by FCRG personnel in six cruises during the past year.

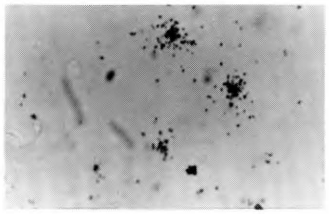
The Regional Marine Program on plankton dynamics in the Southern California Bight ranges from shallow coastal waters of the shelf to deep basins on the continental borderland. These studies have included time series of plankton production, plankton abundance and distribution, plant nutrient concentrations, and physical/chemical oceanographic measurements. This year Dr. Paul Smith, National Marine Fisheries Service, and Dr. Richard W. Eppley discovered that 60 percent of the variability in plankton primary production is accounted for by two ocean climate variables: the anomaly in sea-surface temperature and the seasonally changing length of day.

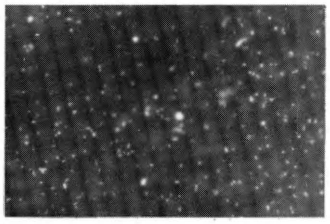
Unusual oceanographic events often present special opportunities for field observations by FCGR personnel. An intense dinoflagellate bloom (a yellow tide) in La Jolla Bay, and its related temperature and nutrient regimes have been investigated by FCRG scientists. Dr. Mark Huntley examined the feeding behavior of zooplankton on these algae, and graduate student José Palaez-Hudlet studied large-scale water movements as perceived by satellite imagery. The effect of storm activity on the distribution of phytoplankton and zooplankton has also been investigated in the Dana Point region in California.

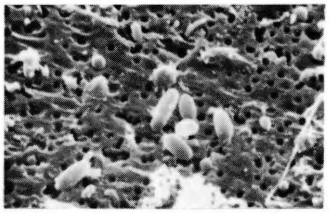
Dr. John R. Beers completed analyses on seasonal observations of the microplankton population abundance and taxonomic structure in the North Pacific Central Gyre. He and colleagues are also completing data analysis of the abundance and composition of phytoplankton associated with macroaggregates (marine snow) in the Southern California Bight. On the average they were found to contain only a small fraction of the total phytoplankton biomass, but nevertheless represent enhanced concentrations of phytoplankton biomass that may be important for grazing organisms.

A technique to determine phytoplankton carbon biomass and in situ specific growth rates has been developed by Dr. Donald G. Redalje. This method, based on the rate of radiocarbon incorporation into chlorophyll *a*, has been tested under controlled conditions in the laboratory and has been used to study phytoplankton population dynamics in coastal environments.

Dr. Michael M. Mullin and his colleagues have developed techniques for the laboratory rearing of the marine zooplankter *Penilia avirostris* with the goal of estimating rates of feeding,







Dr. Angelo F. Carlucci prepares an "In Situ Unit" for launch. This unit is used to study bacterial activity in surface films. Photos at right are representative of observations obtained when the In Situ Unit is used. At top right is a microautoradiograph of metabolizing bacteria. The dark specks are silver grains exposed by tritium radiation from labeled organic substrates taken up by surface-film bacteria. At center right is an epifluorescence micrograph of bacteria stained with acridine orange that binds to the DNA in the bacteria (light flecks) and fluoresces when excited with blue light. This technique is used to enumerate bacteria. At bottom right is a scanning electron micrograph of surface-film bacteria, magnification 8000x.

growth, and birth under known conditions in the laboratory. Thus, rates for the wild population can be interpolated and used to calculate secondary production. Dr. Mullin and graduate student Kenneth E. Richter have also continued development of a high-frequency, dual-beam acoustic system to determine small-scale horizontal and vertical patches of several sizes of zooplankton.

Dr. Huntley conducted a six-week population-dynamics experiment in the SIO Deep Tank with the copepod *Calanus pacificus* to determine secondary productivity directly (by analysis of cohorts) and indirectly (from temperature, food supply, and the size distribution of the animals).

Dr. Farooq Azam and graduate student Jed A. Fuhrman have developed a method to measure the rates of bacterioplankton secondary production in natural seawater samples. The method is based on measurement of the rate of DNA synthesis by [^{3}H]-labeled thymidine incorporation. This method was employed to identify the environmental factors that influence bacterioplankton growth in the Southern Caifornia Bight area and in Antarctic waters. The scientists have also shown that free-living bacterioplankton dominate microbial metabolism in the pelagic environments. Other work in progress involves study of mechanisms for sugar transport, and the possible regulatory role of cyclic adenosine monophosphate in marine bacterial metabolism.

The role of bacteria in transformations of dissolved organic matter in the sea is being evaluated by Dr. Angelo F. Carlucci. Measurement of assimilation rates of organic substrates, as well as results from microautoradiographic and epifluorescence microscopy, indicates that the highest concentrations and activities of bacteria are associated with the subsurface chlorophyll maximum, which often does not coincide with the depth of maximal primary production. Other studies have shown that bacteria tend to be concentrated and to be active in sea-surface films, in spite of the bactericidal effect of solar radiation.

Dr. Osmund Holm-Hansen and colleagues have continued their studies on the distribution and concentration of organic matter in the water column and in sediments, and on the rate of transport of organic matter from the euphotic zone to deeper waters. Particle Interceptor Traps have been deployed by graduate student Dwight D. Wahlberg to collect material falling through the water column; this material is then chemically and biologically characterized.

Determination of the distribution of organic matter between the colloidal and dissolved fractions in surface water and water at 500-m depth was completed by Dr. Peter M. Williams. Colloidal and dissolved organic carbon account for approximately 20 and 70 percent of the total organic carbon, respectively. In collaboration with Dr. Susan M. Henrichs, a new project has been initiated to analyze for the free, combined, and particulate amino acids and carbohydrates in coastal waters. These analyses are particularly important for microbial studies of bacterial heterotrophy and for monitoring excretion of organic matter by phytoplankters and zooplankters.

These organic compound determinations are also part of a program concerned with natural sea-surface films. Film studies include chemical composition, film formation rates, and various physical-chemical properties for natural and laboratory-generated surface films. Dr. Williams is also exploring the nature of the food chain in specialized deep-sea environments. Organic ^{14}C activities and ^{13}C/^{12}C ratios determined on mussel and tube-worm tissues collected from the Galápagos hydrothermal vents support the hypothesis that the primary dietary carbon source for these organisms is chemoautotrophic bacteria that synthesize organic carbon in either the effluent waters of the vents (mussels) or as symbionts in the tube worms.

In addition to directing physical oceanographic measurements in the Southern California Bight studies, Dr. George A. Jackson has been looking for structure in coastal currents associated with topographic features in southern California. He is using hydrographic techniques to look for discontinuities that indicate such processes. Drs. Jackson and Clinton D. Winant have been measuring currents in and near kelp beds to determine how a kelp bed affects its physical environment. Results show that currents within the kelp bed are significantly slower than outside. Changes in the physical regime in the bed affect the supply of nutrients to the kelp and also the growth of planktonic larvae that serve as food for kelp-bed animals.

Other IMR Research Activities

Dr. William H. Thomas and associates are investigating the ability of the marine microalga *Phaeodactylum tricornutum* to produce cells that are high in energy content and to measure its efficiency of light utilization and proximate composition. They found that normal *Phaeodactylum* cells mainly produce protein (60 percent of dry weight) with a maximum yield of about 21 gm dry weight/m^2/day and a maximum efficiency of light utilization of about 12.5 percent. This compares with yields of crop plants of about 4-5 gm/m^2/day and efficiencies of 1-3 percent. Under nitrogen-limiting conditions, the cellular energy level increased from 5.0 cal/mg dry weight to 5.7 cal/mg dry weight. The lipid content increased from 20 percent of dry weight to 30 percent, but the overall yield was reduced to about 8 gm dry weight/m^2/day. Thus N-deficiency did not increase the total yield of caloric energy or lipids. Protein content was reduced to 15-20 percent of the dry weight by N-deficiency. Several other algae were found to produce dense cultures.

Other work of Dr. Thomas's group has involved the completion of studies on allelopathic interaction between phytoplankton species and on the effects of petroleum refinery effluent compounds on natural phytoplankton assemblages on an *ad hoc* basis. The group is also looking for significant phytoplankton-nutrient interrelationships in the eastern tropical Pacific Ocean, using the 1967-1968 Eastropac Expedition data base.

Dr. Mizuki Tsuchiya has completed physical oceanographic studies on the equatorial 13°C water of the eastern Pacific, a large body of nearly homogeneous water (temperature about 12.5°C, salinity about 34.9‰) that develops at depths 75 to 300 m beneath the primary thermocline between 5°N and 5°S east of 150°W. By mapping various properties (depth, acceleration potential, salinity, and the like) along an isanosteric surface that coincides with the core of the 13°C water, Dr. Tsuchiya has shown that the original characteristics of the 13°C water are acquired in the surface and thermocline layers to the northeast of New Zealand and in the Tasman Sea by winter convection and vertical mixing. The acquired characteristics are advected to the subthermocline layers of the eastern equatorial Pacific via a long route, first along the South Pacific subtropical anticyclonic gyre and then along the eastward subsurface South Equatorial Countercurrent and Equatorial Undercurrent.

Dr. Tsuchiya is currently working on the circulation of the upper waters of the entire Pacific Ocean. Maps of various properties along the 240 cl t^{-1} isanosteric surface have been completed for both summer and winter. These maps are being used to deduce the circulation in the thermocline layer. Special attention is being paid to the North Pacific subtropical gyre, which exhibits a double-cell structure with a clear offshore return flow of the Kuroshio.

Sargun A. Tont has been studying correlations of alongshore wind stress and upwelling, with significant correlations obtained if wind stress is calculated from measured winds as opposed to variables from geostrophic winds. This finding suggests that geostrophic winds do not necessarily represent actual wind flow in the southern California coastal region. Since upwelling indices are applied in many fields, such as fishery research and environmental studies, Tont has initiated a program in which wind stress for several locations, ranging from Pt. Conception to San Diego, will be calculated for periods during which reliable measurements have been made.

SEAGOING OPERATIONS

R/V *Melville*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
7/2-7/7/80	Student Cruise	Local	SIO Student Cruise	San Diego	R. Dunbar	A. Phinney
7/10-7/20/80	Baja Cruise	Coast of Baja California	Instrument placing; seismographic oper.	San Diego, La Paz	J. Orcutt, K. Macdonald	A. Phinney
7/21-8/18/80	Baja Cruise	Coast of Baja California, Guyamas Basin	Deep Tow survey & samp. of hydrothermal fields	La Paz, Cabo San Lucas, San Diego	P. Lonsdale	A. Phinney
8/28-8/30/80	Vulcan Leg 0	Local	Testing	San Diego	R. Weiss	A. Phinney
9/3-9/30/80	Vulcan Leg 1	West coast of S. America	Manganese nodule project	San Diego, Callao, Peru	M. Lyle (OSU), R. Rosson	A. Phinney
10/4-10/23/80	Vulcan Leg 2	West coast of S. America	Dredging of Chile trench	Callao, Antofagasta	K. Scheidegger	A. Phinney
11/5-11/10/80	Vulcan Leg 3	West coast of S. America	Resolution of lateral/vertical variation of Chile trench	Antofagasta, Valparaiso	V. Kulm (OSU)	A. Phinney
11/10-11/28/80	Vulcan Leg 4	West coast of S. America	Same & seismic reflections & bottom coring	Valparaiso (twice)	V. Kulm	A. Phinney
12/1/80-1/11/81	Vulcan Leg 5	S. Atlantic	Petrologic variation So. Amer./Antarctic ridge	Valparaiso, Punta Arenas	H. Dick (WHOI)	A. Arsenault
1/20-2/20/81	Vulcan Leg 6	Scotia Sea	Physical/chem./biol. oceanographic study	Punta Arenas (twice)	T. Foster	A. Arsenault
2/25-3/27/81	Vulcan Leg 7	Scotia Sea, Antarctic Pen.	Biol. study of structure/ character of water mass properties/mixing	Punta Arenas (twice)	O. Holm-Hansen	R. Haines
3/28-4/3/81	Vulcan Leg 7	S. Pacific Ocean	Transit	Punta Arenas, Valparaiso	——	R. Haines
4/14-5/14/81	Vulcan Leg 8	S. Pacific Ocean	Angus survey/EPR axis basalt samples/hydrothermal coring	Valparaiso, Nuku Hiva	H. Craig, R. Ballard (WHOI)	R. Haines
5/15-5/26/81	Vulcan Leg 8B	S/N Pacific Ocean	Hydrographic casts	Nuku Hiva, San Diego	F. Dixon	R. Haines

TOTAL DISTANCE STEAMED: 33,982 nautical miles OPERATING DAYS: 301

R/V *Thomas Washington*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
7/1-7/21/80	Rama Leg 4	Northwest Pacific	Current meter moorings laid/CTD casts/routine bathy-metry & magnetometer tows	Yokosuka, Japan, Apra Harbor, Guam	K. Bradley (WHOI)	A. Aresnault
8/23-9/4/80	Rama Leg 5	Sunda Strait, Sulawesi Sea	Structure of Sunda Strait & Sulawesi Sea sediments	Guam, Surabaya, Indonesia	J. Curray, G. Moore	A. Aresnault
9/12-9/29/80	Rama Leg 5A	South Java coast	Reflection & refraction survey	Surabaya, Padang	J. Curray, G. Moore	C. Johnson
9/30-10/27/80	Rama Leg 6	Nias Islands	Reflection & refraction survey	Padang, Singapore	G. Shor, G. Moore	C. Johnson
10/31-12/2/80	Rama Leg 7	Philippines & Marianas Trench	Biological study/rock dredging	Singapore, Guam	A. Yayanos	C. Johnson
1/5-1/28/81	Rama Leg 8	Marianas	Deep Tow geology/geophysics	Guam (twice)	P. Lonsdale	K. Pulsifer
1/31-2/17/81	Rama Leg 9	Philippine Sea	Seismic wave propagation/ sound propagation	Guam (twice)	L. Dorman, D. Bibee (OSU)	L. Davis
2/20-3/8/81	Rama Leg 10	Marianas Trench	Bottom navigated heat flows & coring surveys, hydrothermal deposits	Guam (twice)	R. Anderson (LDGO), M. Bender (URI)	L. Davis
3/10-3/26/81	Rama Leg 11	Philippine Sea	Ocean bottom seismology	Guam, Cebu, P.I.	L. Dorman, D. Bibee (OSU)	A. Arsenault
3/30-5/5/81	Rama Leg 12	Eastern Sunda Arc	Seismic reflection	Cebu, P.I., Guam	E. Silver (UCSC)	A. Arsenault
5/10-6/2/81	Rama Leg 13	N. Pacific Ocean	Service moorings/redeploy CTD casts	Guam, Adak, Alaska	A. Ciesluk (WHOI)	C. Johnson
6/6-6/19/81	Rama Leg 14	N. Pacific Ocean	Deploy long-term measure-ment moorings/CTD casts	Adak, Dutch Harbor, Alaska	B. Owens (WHOI)	C. Johnson
6/20-7/2/81	Rama Leg 15	N. Pacific Ocean	Various water samples/ deploy, recover fish traps	Dutch Harbor, San Diego	J. Burke (WHOI)	C. Johnson

TOTAL DISTANCE STEAMED: 39,049 nautical miles OPERATING DAYS: 301

R/V *Ellen B. Scripps*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
7/3-7/4/80	Bada Cruise	Local	Water sampling	San Diego	J. Bada	C. Johnson
7/8/80	Cox Cruise	Local	Instrument test	San Diego	C. Cox	C. Johnson
7/9/80	Cox Cruise	Local	Instrument test	San Diego	C. Cox	C. Johnson
7/12/80	Student Cruise	Local	Hydro casts/grab samples/net tows	San Diego	R. Dunbar	C. Johnson
7/17/80	Cox Cruise	Local	Instrument tests	San Diego	C. Cox	C. Johnson
7/19-7/23/80	Prothero Cruise	Santa Barbara Channel	Retrieve & service OBS	San Diego, Pt. Hueneme, San Diego	W. Prothero (UCSB)	R. Haines
8/4-8/8/80	Cox Cruise	Local	Plankton pumping, CTD, net trawl, Niskin cast	San Diego	J. Cox (UCSB)	R. Haines
8/12/80	Winant Cruise	Local	Current meter & hydrographic work	San Diego	C. Winant	R. Haines
8/12-8/15/80	Sullivan Cruise	Local	Free vehicle set lines, bottom trawling	San Diego	K. Sullivan	R. Haines
8/18-8/19/80	Anderson Cruise	Local	Sea test buoys	San Diego	V. Anderson	R. Haines
8/20-8/22/80	Yayanos Cruise	Local	Biological sampling	San Diego	A. Yayanos	R. Haines
8/25-8/29/80	Prothero Cruise	Local	Deploy & retrieve OBS	San Diego	W. Prothero (UCSB)	A. Arsenault
9/3-9/10/80	Winant Cruise	Local	Recover/deploy current meters	San Diego	C. Winant	G. Clark
9/15-9/17/80	Winant Cruise	Local	Recover/deploy current meters	San Diego	C. Winant	G. Clark
9/22/80	Worcester Cruise	Local	Physical ocean. equip. test	San Diego	P. Worcester	A. Arsenault
9/23-9/25/80	Wilson Cruise	Local	Free vehicle set lines & bottom trawling	San Diego	R. Wilson	A. Arsenault
10/3-10/24/80	A^3 Sea Test	Calif. coast	Acoustic tests	San Diego, Monterey, San Diego	B. Parks (NOSC)	G. Clark
11/4-11/6/80	Wilson Cruise	Local	Benthic biology	San Diego	R. Wilson	R. Haines
11/15/80	Student Cruise	Local	Benthic bio./sampling	San Diego	A. Fleminger	T. Whitman
12/8-12/9/80	Sullivan Cruise	Local	Bio. sampling/floor to surface	San Diego	K. Sullivan	T. Whitman
1/21/81	Natl. Acad. of Sci.	Local	Training Cruise	San Diego	R. Revelle	T. Whitman
1/27-1/28/81	Lange Cruise	Local	Subsurface vehicle tow	San Diego	E. Lange	T. Whitman
1/30-2/2/81	Austin Buoy	Local	Subsurface buoy implant	San Diego	R. Austin	T. Whitman
2/3-2/5/81	Aumann Cruise	Local	Bio. sampling	San Diego	M. Aumann	T. Whitman
3/9-3/11/81	Sullivan Cruise	Local	Bio. sampling	San Diego	K. Sullivan	T. Whitman
3/20-4/1/81	CODE Buoy	Calif. coast	CODE buoy deployment	San Diego, Yerba Buena, San Diego	C. Winant	T. Whitman
4/7/81	Richter Cruise	Local	Zooplankton research	San Diego	K. Richter	T. Whitman
4/9-4/10/81	Sullivan Cruise	Local	Benthic boundary layer energetics	San Diego	K. Sullivan	T. Whitman
4/16/81	——	Local	Equipment search	San Diego	K. Richter	T. Whitman
4/20-4/23/81	Sullivan Cruise	Local	Bio. sampling/hydrocast	San Diego	K. Sullivan	T. Whitman
4/27-5/1/81	Prothero seismic	Santa Barbara area	Seismic evaluations	San Diego, Pt. Hueneme, Santa Barbara, Pt. Hueneme, San Diego	W. Prothero (UCSB)	T. Whitman
5/5-5/6/81	Wilson Cruise	Local	Sabrat-pressure trap deployment	San Diego	R. Wilson	T. Whitman
5/18-5/19/81	Smith Cruise	Local	Recover vehicles	San Diego	C. Smith	T. Whitman
6/1-6/30/81	Le Boeuf Cruise	Baja Calif.	Sea lion study	San Diego, La Paz, Guaymas, La Paz, San Diego	Le Boeuf (UCSC)	T. Whitman

TOTAL DISTANCE STEAMED: 13,216 nautical miles OPERATING DAYS: 141

R/V *New Horizon*

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
6/30-7/2/80	Hayward Test	Local	Testing	San Diego	T. Hayward	L. Davis
7/12-7/29/80	Northeast Pac. Leg 1	Pacific Ocean	Deploy magnetic & pressure recorders for magnetotelluric exploration/ocean tides	San Diego, Honolulu	J. Filloux	L. Davis
8/10-9/3/80	Northeast Pac. (FIONA)	N.E. Pacific Ocean	Bottle casts to measure salinity vs. temp. & depth	Honolulu, Coos Bay	T. Hayward	L. Davis
9/7-10/1/80	Northeast Pac.	N.E. Pacific Ocean	Benthic community metabolism	Coos Bay, San Diego	K. Smith	L. Davis
10/4-10/13/80	Carlucci/ Williams	Local	Chemistry & microbio. of surface film formation & alteration	San Diego	A. Carlucci, P. Williams	A. Arsenault
10/15-10/27/80	SCIB-SI	Local	Bio./physio./ocean. of Calif. offshore islands	San Diego	L. Haury	A. Arsenault
11/1-11/15/80	Cox/Regier	Local	Launch & recover current meter pkg./cartesian diver	San Diego	C. Cox, L. Regier	K. Pulsifer
11/19-12/2/80	Northeast Pac. Leg 2	Local	Vehicle recovery	San Diego	J. Filloux	L. Davis
12/8-12/20/80	CalCOFI 8012 NH	Local	Nansen bottle casts/Manta tows/weather	San Diego	R. Mead	L. Davis
1/7-1/25/81	C2FP2	Local	Bio./chem./physical surveys	San Diego	J. Simpson	L. Davis
1/28-2/9/81	Smith Cruise	Local	Floor to surface biological sampling	San Diego	K. Smith	A. Phinney
2/10-2/11/81	MANOP Lander	Local	MANOP Lander test	San Diego	R. Weiss	K. Pulsifer
2/12-2/21/81	CalCOFI 8102 NH	Local	Collect bio. samples/data from CTD casts	San Diego	J. Schmitt	A. Phinney
2/24-3/8/81	CalCOFI 8102 NH	Local	Marine life research	San Diego	J. Schmitt	A. Phinney
3/16-3/28/81	Childress Cruise	Local	Bottom & midwater trawl	San Diego	J. Childress (UCSB)	A. Phinney
4/7-4/28/81	CalCOFI 8104 NH	Local	Phys./chem./biol. ocean. food chain	San Diego	J. Costello	L. Davis
5/5-5/12/81	Mullin Cruise	Local	Plankton sampling, South. Calif. Bight	San Diego	M. Mullin	L. Davis
5/19-6/8/81	CalCOFI 8105 NH	Local	Phys./chem./bio. ocean.	San Diego	D. Muus	L. Davis
6/12-6/25/81	Smith Cruise	Local	Floor to surface bio. sampling	San Diego	K. Smith	L. Davis
6/29-6/30/81	Weiss equip. test	Local	Equipment tests	San Diego	R. Weiss	L. Davis

TOTAL DISTANCE STEAMED: 31,735 nautical miles OPERATING DAYS: 272

R/P FLIP

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
3/27-4/4/81	OP 133.0	Local	Precision acoustic measurements	San Diego	R. Pinkel	D. Efird
4/13-4/24/81	OP 134.0	Local	Coop. acoustic measurements	San Diego	R. Tyce	D. Efird

OPERATING DAYS: 21

R/P ORB

DATE	EXPEDITION	AREA OF OPERATION	WORK PERFORMED	PORTS OF CALL	CHIEF SCIENTIST	CAPTAIN
12/9-12/18/80	OP 77.0	Local	Acoustic research ORB/ADA Operation	San Diego	V. Anderson	T. Hoopes
5/18-5/29/81	OP 78.0	Local	Acoustic scattering measurements	San Diego	T. Muir (U. of Texas)	T. Hoopes
6/14-6/27/81	OP 79.0	Local	Bunker-Ramo instrument tests	San Diego	J. Moll	T. Hoopes

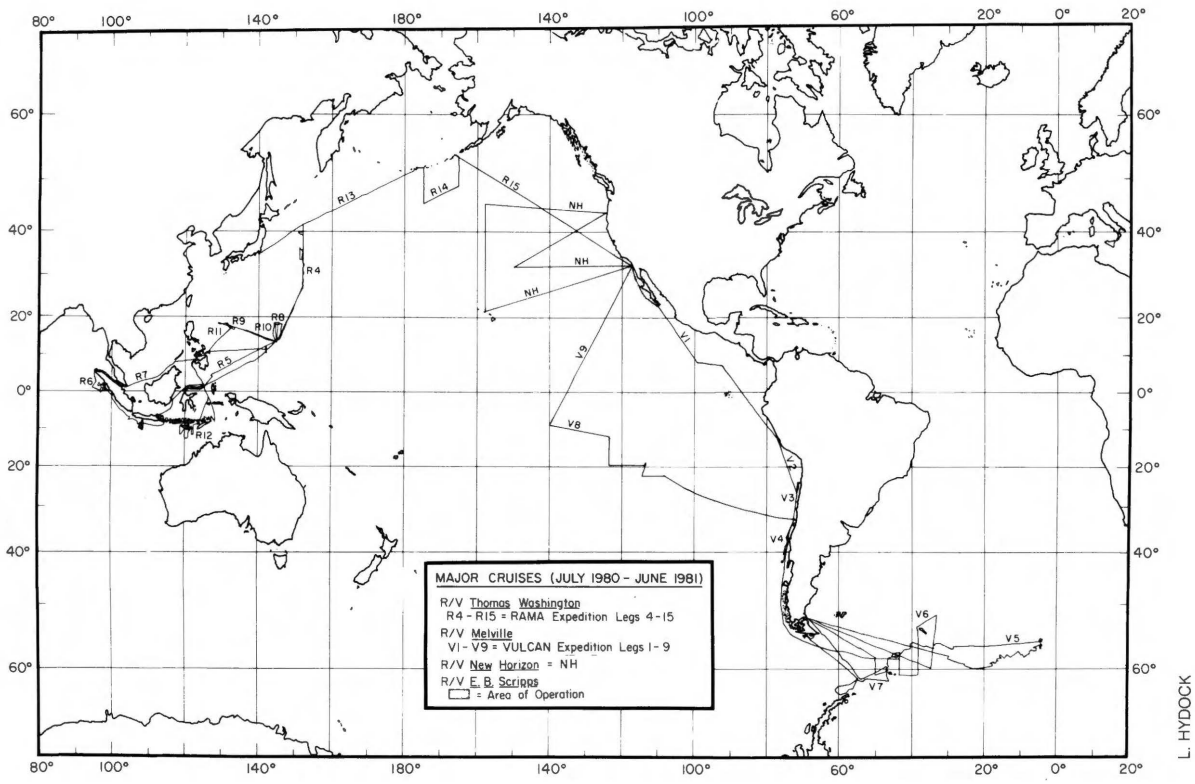
TOTAL DISTANCE TOWED: 100 nautical miles OPERATING DAYS: 36

RESEARCH VESSELS OF SCRIPPS INSTITUTION OF OCEANOGRAPHY

	MELVILLE	*NEW HORIZON*	*ELLEN B. SCRIPPS*	*THOMAS WASHINGTON*	FLIP	ORB
TYPE:	Oceanographic research	Oceanograhic research	Offshore supply	Oceanographic research	Floating Instrument Platform	Oceanographic Research Buoy
HULL:	Steel	Steel	Steel	Steel	Steel	Steel
YEAR BUILT:	1969	1978	1964-65	1965	1962	1968
YEAR ACQUIRED BY SCRIPPS:	1969	1978	1965	1965	1962	1968
OWNER:	U.S. Navy	University of California	University of California	U.S. Navy	U.S. Navy	U.S. Navy
LENGTH:	74.67 m	51.81 m	28.95 m	63.70 m	108.20 m	21.03 m
BEAM:	14.02 m	10.97 m	7.31 m	12.00 m	6.09 m	13.71 m
DRAFT:	4.87 m	3.65 m	1.82 m	4.39 m	3.35/91.44 m	fwd. 1.48 m aft. 1.63 m
DISPLACEMENT FULL (Metric Tons):	1,882	698	212	1,235	1,359	294
CRUISING SPEED (Knots):	10	10.5	9	11	varies*	varies*
RANGE (Nautical miles):	9,181	7,000	5,100	10,000	varies*	varies*
CREW:	22	12	5	21	6	5
SCIENTIFIC PARTY:	28	13	8	21	10	10

1980-81 Total days at sea: 1015
1980-81 Total nautical miles steamed: 117,982
*Depends on towing vessel

Track chart



L. HYDOCK

Scientists draining water from Nisken bottles mounted on the CTD-Rosette aboard R/V Melville *in the Antarctic during the Vulcan Expedition.*

P. R. STEVENS

R/V Melville *silhouetted against an iceberg in the Antarctic during the Vulcan Expedition.*

P. R. STEVENS

GRADUATE DEPARTMENT

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

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

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

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

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

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

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

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

GRADUATE STUDENTS AND DEGREE RECIPIENTS

In the fall of 1980, 37 new students were admitted to graduate study. Of these, 11 were in marine biology, 7 in geological sciences, 2 in marine chemistry, 4 in geophysics, 4 in physical oceanography, 5 in applied ocean sciences, and 4 in biological oceanography. Enrollment at the beginning of the academic year was 189. Ten Master of Science degrees and 21 Doctor of Philosophy degrees were awarded by UC San Diego to the students listed.

Doctor of Philosophy Degrees Awarded, with Titles of Dissertations

Earth Sciences

Richard W. Carlson, "Crust - Mantle Differentiation on the Earth and Moon: Evidence from Isotopic Studies for Contrasting Mechanisms and Duration."

Stephen E. Crane, "Structural Chemistry of the Marine Manganate Minerals."

Robert D. Francis, "On the Fractionation of Sulfur, Copper, and Related Transition Elements in Silicate Liquids."

Randall S. Jacobson, "Linear Inversion of Body Wave Data."

Keith A. Sverdrup, "Seismotectonic Studies in the Pacific Ocean Basin."

John A. Welhan, "Carbon and Hydrogen Gases in Hydrothermal Systems: The Search for a Mantle Source."

Marine Biology

Michael A. Castellini, "Biochemical Adaptations for Diving in Marine Mammals."

John E. Graves, "The Taxonomic and Functional Significance of Protein Variation in Some New World Marine Fishes."

Robert J. Olson, "Studies of Biological Nitrogen Cycle Processes in the Upper Waters of the Ocean, with Special Reference to the Primary Nitrite Maximum."

Patrick J. Walsh, "Temperature Adaptation in Sea Anemones (Anthozoa; Cnidaria): Molecular Mechanisms and Evolutionary Perspectives."

Oceanography

Charles M. Alexander, "The Complex Vibrations and Implied Drag of a Long Oceanographic Wire in Cross-Flow."

William C. Bartram, "The Feeding Response of Two Neritic Copepods to Changes in the Composition of Their Food."

John J. Cullen, "Chlorophyll Maximum Layers of the Southern California Bight and Mechanisms of Their Formation and Maintenance."

Sarah L. French, "Mechanism of Halotolerance in Some Manganese Oxidizing Bacteria."

William H. Gerwick, "The Natural Products Chemistry of the Dictyotaceae."

Paul R. Greenblatt, "Observations of Zooplankton Patchiness Using a High Frequency Sonar and a Multiple Sample Plankton Net."

David Sheres, "Remote Synoptic Surface Flow Measurements in Small Bodies of Water."

John L. Spiesberger, "Stability of Long Range Ocean Acoustic Multipaths."

Jeffrey L. Star, "Variation and Covariation in the Plankton of the Euphotic Zone in the North Pacific Ocean."

Francisco V. Vidal Lorandi, "Part I—The Metabolism of Arsenic in Marine Bacteria and Yeast. Part II—Stable Isotopes of Helium, Nitrogen and Carbon in the Geothermal Gases of the Subaerial and Submarine Hydrothermal Systems of the Ensenada Quadrangle in Baja California Norte, Mexico. Part III—Life at High Temperatures in the Sea: Thermophilic Marine Bacteria Isolated from Submarine Hot Springs, Coastal Seawater and Heat Exchangers of Seawater Cooled Power Plants."

Bruce A. Wielicki, "An Analysis of Cloud Property Retrieval Using Infrared Sounder Data."

Master of Science Degrees

Earth Sciences

William S. Harvie
Char-Shine Liu
Mark A. Riedesel

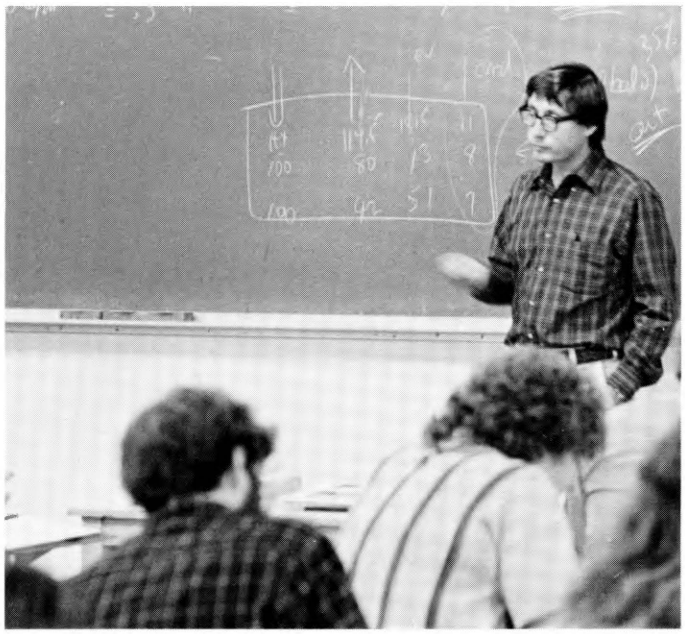
Marine Biology

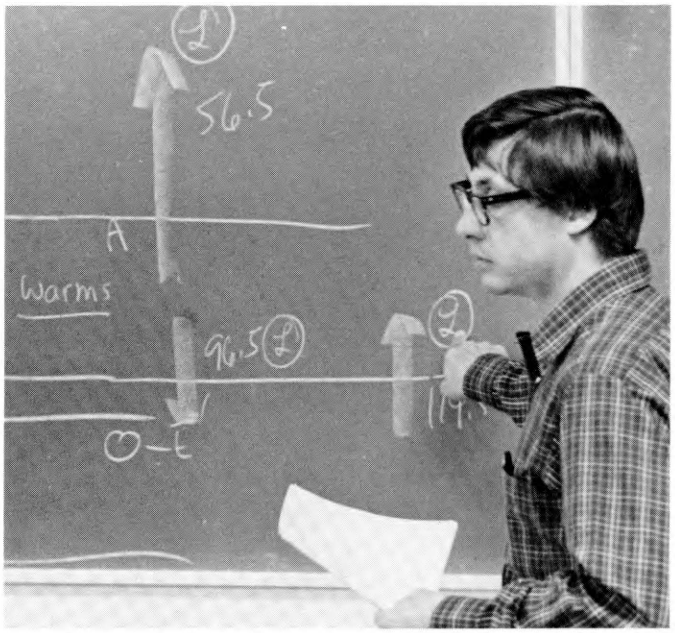
Dana M. Austin
Kenneth N. Sokolski
Katie L. Turner

Oceanography

Francisco Arredondo
Mark R. Legg
Christine Provost
Barbara A. Price

Dr. Myrl C. Hendershott teaching his physical oceanography class.





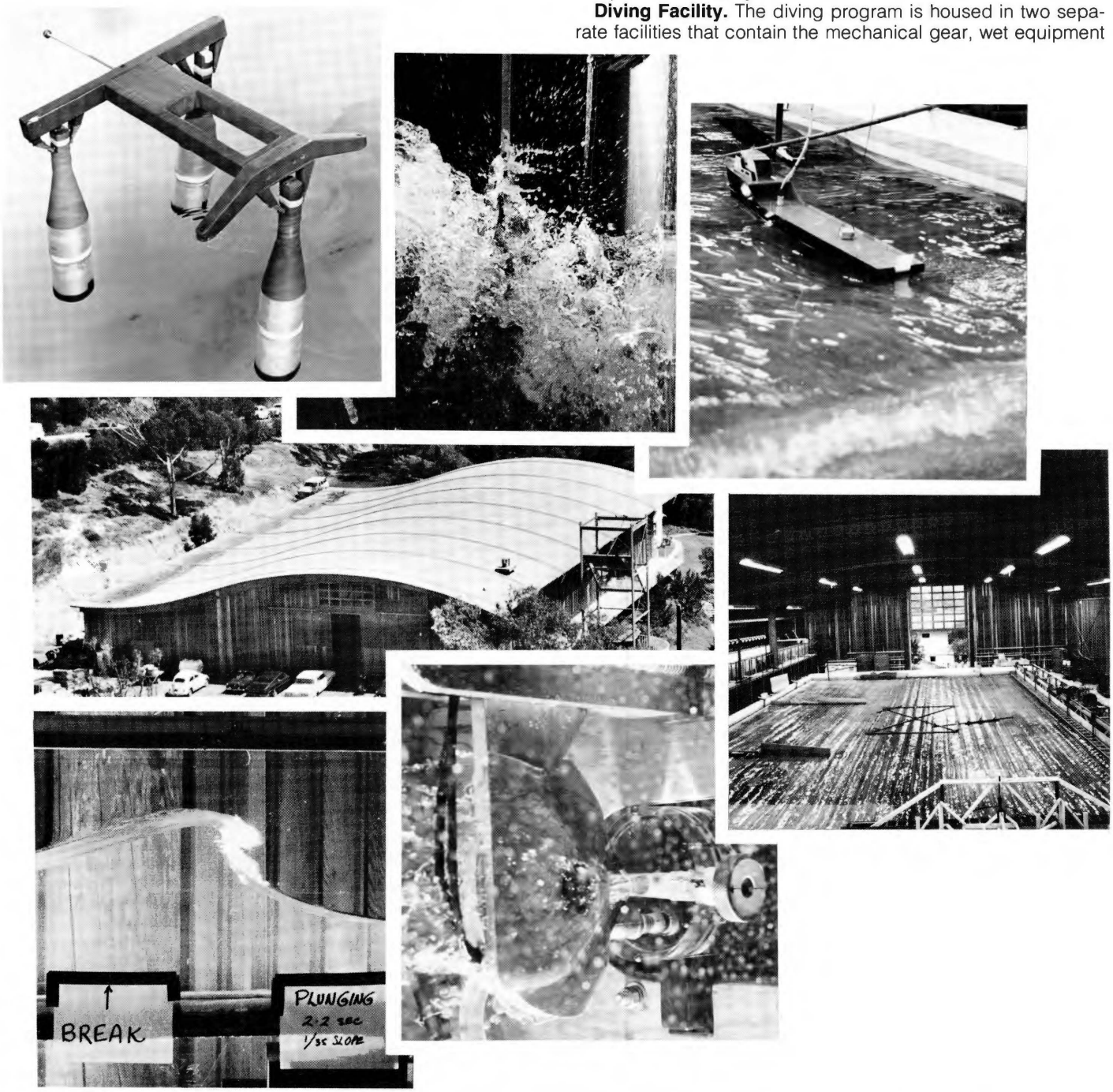
SHORE FACILITIES AND SPECIAL COLLECTIONS

Facilities

Analytical Facility. Instruments at the facility include an automated X-ray diffractometer; automated X-ray spectrometer; Atomic Absorption Spectrometer (A.A.); heated graphite atomizer (attachment to A.A.); amino-acid analyzer; gas chromatograph; gas chromatograph/mass spectrometer; carbon-dioxide analyzer; a Cambridge S-4 scanning electron microscope with energy dispersive X-ray spectrometer; a Hitachi H-500 STEM with energy dispersive X-ray spectrometry and CAMECA 3-scanner electron microprobe. The facility offers complete sample preparation laboratories, including "wet" chemistry and rock-processing laboratories, a tabletop HP-97 computer, and geological field equipment.

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

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



The Hydraulics Facility, part of the Center for Coastal Studies, is shown above surrounded by insets of the various experiments conducted there. Clockwise from top left are: a scale-model experiment with a stable floating island; a turbulent wave breaking experiment; an experiment with a scale model of a cargo landing craft in the experimental wave basin; a crescentic bar experiment also in the experimental wave basin; a jet calibration of instruments; and a plunging wave experiment.

storage locker, and showers.

Scripps's scientific diver-training program, the oldest of its type in the country, provides training for Scripps scientists and technicians. There are, on an average, 130 Scripps faculty, staff, and students who dive in all the oceans of the world, including the Antarctic.

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

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

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

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

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

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

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

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

San Vicente Lake Calibration Facility. (48 km from Scripps.) This facility, operated by the Marine Physical Laboratory, is equipped for testing and calibrating acoustic transducers used in oceanographic research. The equipment is located on an 8x15-m enclosed platform in 40 m of water and offers 1,372 m of unobstructed range.

Satellite-Oceanography Facility. This facility provides investigators in the oceanographic community with the means to directly receive and process satellite imagery. Data transmitted in real time by the NOAA and NIMBUS polar orbiting satellites are received by the 5-m tracking antenna and stored on computer-compatible tapes. In addition to real-time coverage, retrospective archives of worldwide data are also available to investigators. The most commonly used sensors include the Advanced Very High Resolution Radiometer (AVHRR) and Coastal Zone Color Scanner (CZCS), which provide information in the infrared and visible portions of the spectrum. The Scanning Multichannel Microwave Radiometer (SMMR) data, from which sea surface winds may be derived, are also processed at the facility. The System Central Processor is a HP 3000 Series II computer dedicated to the facility. This processor has 512 kilobytes of main memory and 250 megabytes of disk storage. Tape drives capable of operating at 800, 1600, or 6250 bpi densities 125 inches per second assure complete versatility. A high resolution color display station allows the user full interaction with the satellite imagery at near-real-time rates for most common operations. Current applications include tracking of drifting buoys via the ARGOS data collection system, near-real-time support of research vessels and aircraft by remote detection of chlorophyll concentrations and sea-surface temperature determination. A four-day course, taught every quarter by the facility staff, gives potential users an overview of the available tools as well as several hours of hands-on experience.

Scripps Library. The library has outstanding collections in oceanography, marine biology, and marine technology. It also specializes in publications on atmospheric sciences, fisheries, geology, geophysics, and zoology. The library currently receives more than 3400 serial titles and has a catalogued collection of 234,000 volumes, including an extensive Documents, Reports, and Translations Collection, a Maps and Charts Collection emphasizing nautical information, and a Rare Book Collection with numerous accounts and journals of famous voyages of discovery.

Scripps Pier. The 305-m pier serves as a launching site for small boats used for local oceanographic work and provides space for on-site observational studies.

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

Seawater flume liner being installed on the Scripps Pier in the spring of 1981.

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

Digital seismic-reflection systems are available to sample either 2 or 24 analog signals and record them on digital magnetic tape.

A Prime 750 computer system on campus is well adapted to economical number-crunching with a 3.2 μs floating point (64 bits) multiplier, two megabytes of memory, 600 megabytes of disk and an array processor. Its use is primarily by CRT terminals.

Thomas Wayland Vaughan Aquarium-Museum. The aquarium-museum increases public understanding and appreciation of the ocean through exhibits of living marine animals, museum displays, and a variety of educational programs.

Scientists at the aquarium-museum study marine animal maintenance systems, fish coloration, and fish diseases. Through the collecting facility, several thousand specimens are supplied each year to Scripps scientists.

This year more than 43,000 students in educational groups toured the aquarium-museum. It is open to the public daily; admission is free.

Underwater Research Areas include:

Ecological Reserve. The 580-acre San Diego-La Jolla Ecological Reserve was established by the city of San Diego and the California Department of Fish and Game primarily for conservation and is protected from any collecting. It has shown measurable return to its pristine condition.

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

Scripps Submerged Land Area. This area of approximately 2.5 km is leased by the University of California from the city of San Diego. It lies seaward and to the north of Scripps.

Special Collections

Benthic Invertebrates. The collection contains some 28,000 lots of specimens sorted into major taxonomic groups such as Coelenterata, Echinodermata, and Mollusca. All are catalogued with collection data, and more than 35 percent are identified according to species. Specimens are available to qualified students and researchers for study.

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

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

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

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

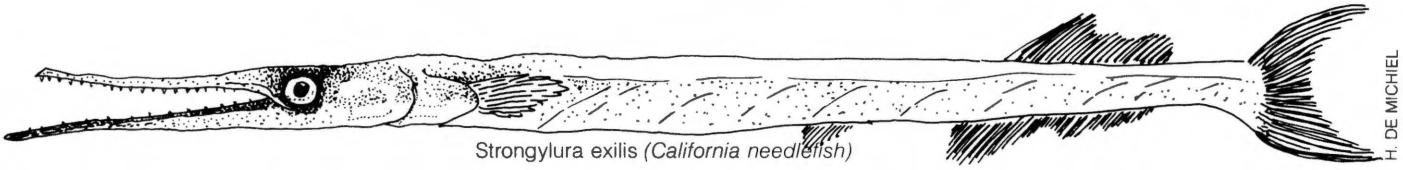
Marine Invertebrates. In this collection of more than 60,000 documented whole zooplankton samples are accessioned holdings from the continuous CalCOFI Program, expeditions, and special projects. Samples represent zooplankton, collected with nets, ranging from surface neuston to bathypelagic mid-water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

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

Oceanographic Data Archives. Tide-gage records have been taken daily from the Scripps Pier since 1925. Starting January 1980, these records are held at the Scripps Diving Locker in one-month data rolls. Records prior to 1980 may be obtained by writing Chief of the Datums and Information Branch, James R. Hubbard, C-233, NOAA/NOS, 6011 Executive Blvd., Rockville, MD 20852.

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

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



Strongylura exilis *(California needlefish)*

PUBLICATIONS

Introduction

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

Below is a complete listing of Scripps publications for fiscal 1981. Detailed availability information is included for each series.

Bulletin

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

The volume listed below was published this year.

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

CalCOFI Atlas Series

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

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

The atlas issued this year is listed below.

No. 28 **Hewitt,** R. Distributional atlas of fish larvae in the California Current region: northern anchovy, *Engraulis mordax* (Girard), 1966 through 1979. December 1980. 111p.

Contributions

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

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

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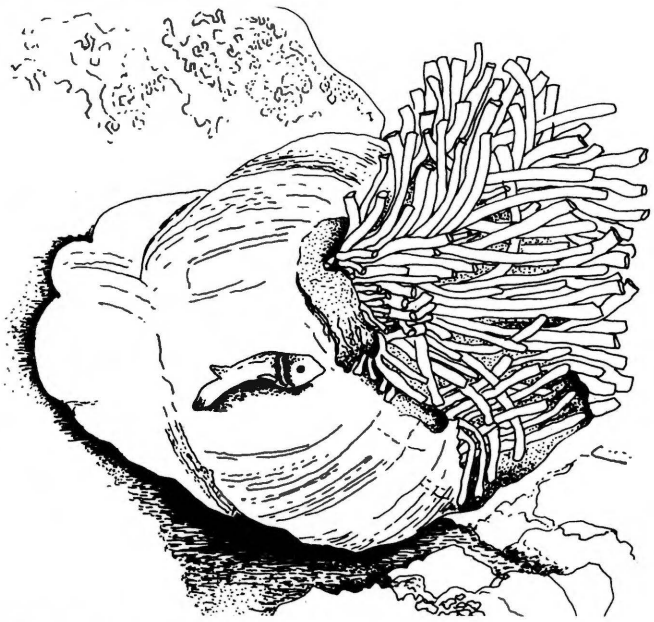

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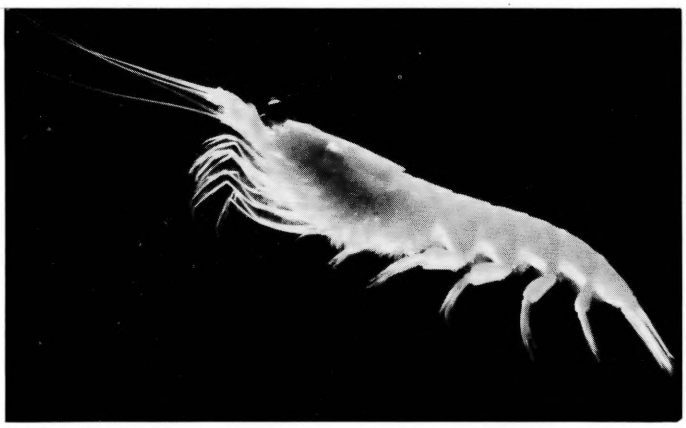

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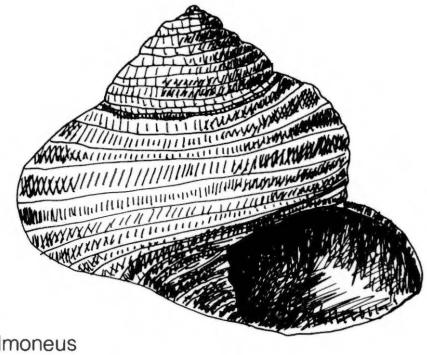

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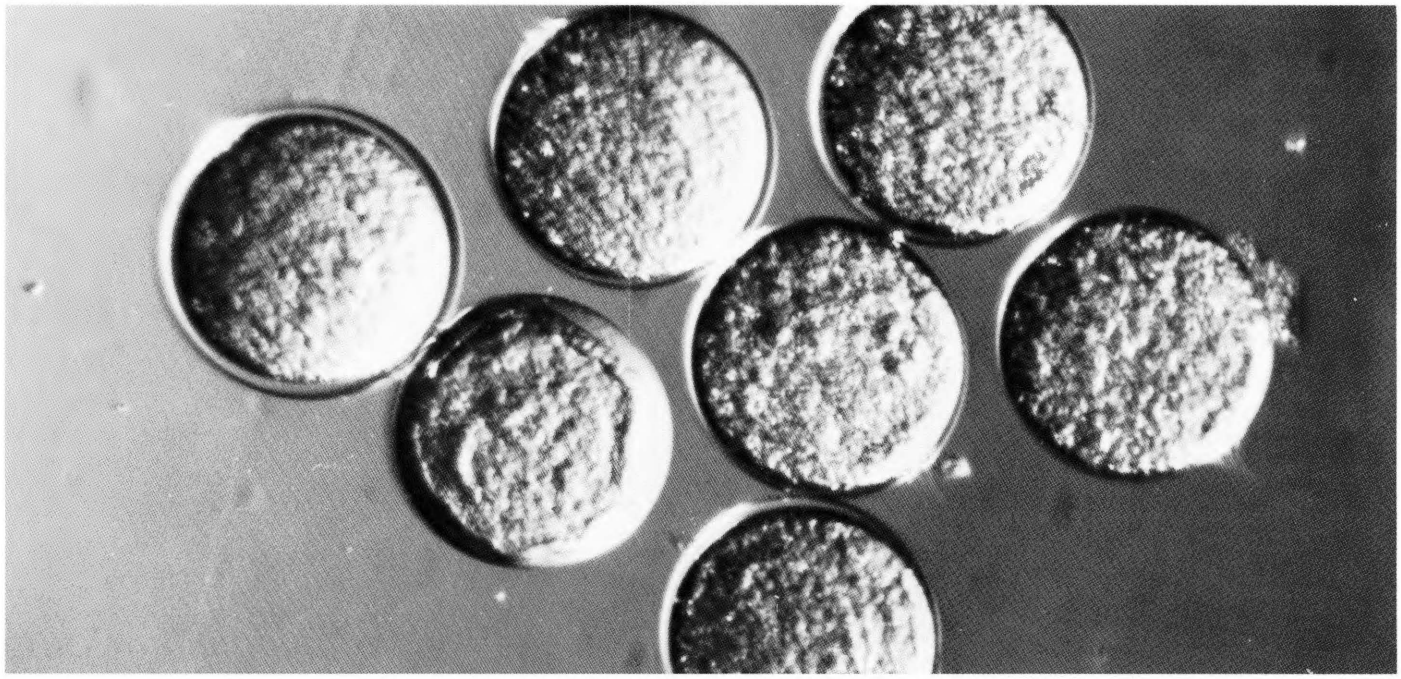

Euphausiid eggs, magnification 400x.

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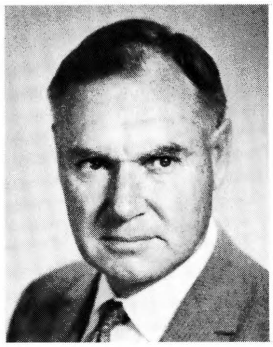
CS—California Space Institute
CCS—Center for Coastal Studies
DO—Director's Office
DSDP—Deep Sea Drilling Project
D-SIO—Department Scripps Institution of Oceanography
EECS—Electrical Engineering and Computer Sciences
GRD—Geological Research Division
IGPP—Institute of Geophysics and Planetary Physics
IMR—Institute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

In Memoriam

Juan Herrera-Lasso. April 9, 1981. He was a graduate student in the marine biology group.

George R. Miller. September 21, 1980. He had been an able seaman at Marine Facilities since May 1977.

Charles Delorma Wheelock. September 21, 1980. Rear Admiral (retired) and professor emeritus, he had joined Scripps in 1953. Admiral Wheelock led the first years of the Institute of Marine Resources, as acting director from 1954 and director from 1958 to 1961. In his 33 years of Navy service he made significant contributions to ship design. Following his retirement from Scripps in 1961, he moved to the Carmel area and served on the Campus Planning Committee of UC Santa Cruz.



Gerald Sheldon Wirth. January 7, 1981. He received his Ph.D. in oceanography at Scripps in 1980 and was on a postdoctoral fellowship at the State University of New York at Buffalo.

APPENDIX A†

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†Current June 30, 1981

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State and Federal Agencies

California, State of
California Space Institute
Water Resources Board

United States
Commerce, Department of
National Oceanic and Atmospheric Administration
Defense, Department of
Air Force
Army, Department of the
Army Corps of Engineers
Defense Mapping Agency
Navy, Office of Naval Research
Energy, Department of
Environmental Protection Agency
Health and Human Services, Department of
National Institutes of Health
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*Anyone interested in making a donation to the institution should contact the Scripps Director's Office, A-010, Scripps Institution of Oceanography, La Jolla, CA 92093.

APPENDIX C

Major Awards and Honors

Dr. Gustaf O. S. Arrhenius
Elected a Fellow of the American Association for the Advancement of Science.

Dr. Patricio A. Bernal
Awarded the Carl Eckart Dissertation Prize by Scripps Institution of Oceanography, University of California, San Diego.

Dr. Ralph J. Cicerone
Elected a Fellow of the American Association for the Advancement of Science.

Dr. James T. Enright
Received a Senior U.S. Scientist Award from the Alexander von Humboldt Foundation to study at the Max Planck Institute for Biophysical Chemistry.
Elected a Fellow of the American Association for the Advancement of Science.

Dr. J. Freeman Gilbert
Received the Gold Medal of the Royal Astronomical Society.

Dr. Harold T. Hammel
Received a Senior U.S. Scientist Award from the Alexander von Humboldt Foundation for study at the Max Planck Institute for Physiological and Clinical Research.
Elected a Fellow of the American Association for the Advancement of Science.

Dr. Charles D. Keeling
Received Second Half-Century Award from the American Meteorological Society.

Dr. J. Anthony Koslow
Received the Fager Memorial Award.

Dr. Walter H. Munk
Awarded a Fulbright-Hayes Fellowship.

Dr. Jerome Namias
Awarded the Harald U. Sverdrup Gold Medal by the American Meteorological Society.

Dr. Kenneth H. Nealson
Awarded a Guggenheim Fellowship.

Dr. William A. Nierenberg
Received honorary Doctor of Science degree from the University of Maryland.
Elected a Fellow of the American Association for the Advancement of Science.

Dr. Fred B Phleger
Received the Joseph A. Cushman Award from the Cushman Foundation for Foraminiferal Research.
Received an honorary appointment to the Universidad Nacional Autónoma de México.

Dr. Francis P. Shepard
Honored by a special symposium to recognize his work as the "father of marine geology."

Dr. Fred N. Spiess
As senior editor, accepted the AAAS-Newcomb Cleveland Prize for the best paper of 1980 published in *Science*. The twenty-one coauthors included seven others from Scripps: Drs. Charles S. Cox, James W. Hawkins, Robert R. Hessler, Miriam Kastner, J. Douglas Macdougall and John A. Orcutt and graduate student Rachel M. Haymon.

Dr. Claude E. ZoBell
Named 1980 Most Distinguished Alumnus of Idaho State University.

APPENDIX D

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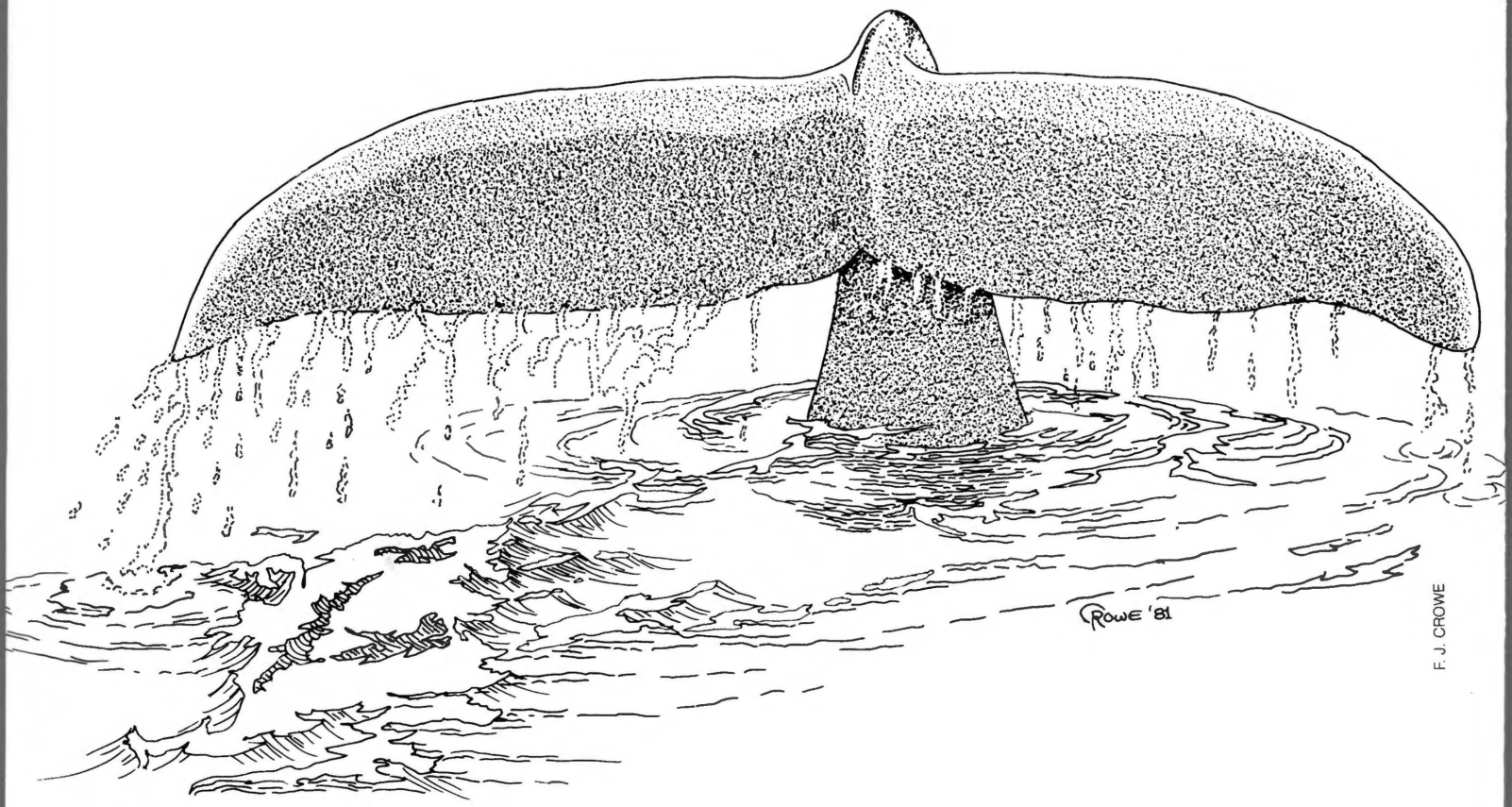
APPENDIX E
Current Funds Expenditures 1980–1981

Agency	Scripps Institution of Oceanography	INSTITUTES Geophysics and Planetary Physics	Marine Resources	Cal Space	Total	Percentage of Total
FEDERAL GOVERNMENT						
National Science Foundation	$30,958,147	660,199	538,453	—	32,156,799	55.5
Navy, Department of the	7,249,580	446,141	18,330	—	7,714,051	13.3
National Oceanic and Atmospheric Administration	—	—	1,653,915	—	1,653,915	2.9
Army, Department of the	—	—	510,054	—	510,054	.9
Energy, Department of	142,522	2,369	504,249	—	649,140	1.1
Air Force, Department of the	486,440	—	—	—	486,440	.8
National Institutes of Health	441,903	1,131	3,818	146	446,998	.8
National Aeronautics and Space Administration	392,886	79,179	—	124,519	596,584	1.0
Other	1,058,806	355,803	—	—	1,414,609	2.4
Total Federal Government	40,730,284	1,544,822	3,228,819	124,665	45,628,590	78.7
STATE AND UNIVERSITY FUNDS	7,589,789	265,417	586,683	402,988	8,844,877	15.3
LOCAL GOVERNMENT	35,258	1,275	—	—	36,533	—
PRIVATE GIFTS AND GRANTS	2,156,026	32,173	179,500	10,989	2,378,688	4.1
ENDOWMENT FUNDS	599,906	44,079	36,706	—	680,691	1.2
SERVICES, RESERVES & MISC.	272,215	19,289	142,483	—	433,987	.7
Total Current Funds Expenditures	$51,383,478	1,907,055	4,174,191	538,642	58,003,366	100.00



F. J. CROWE

Nimitz Marine Facility from the air, all Scripps ships (in foreground) were in port.

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

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