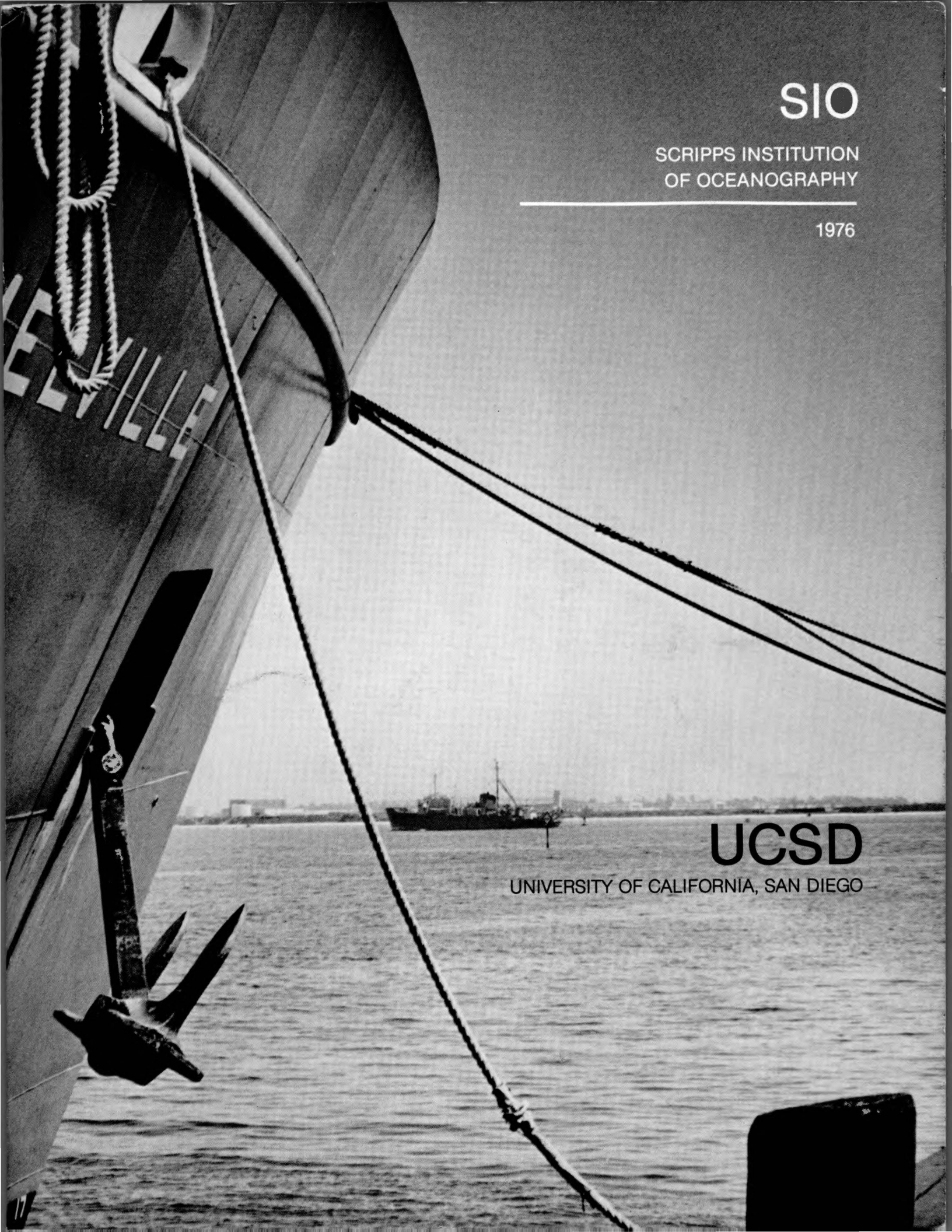

# SIO

SCRIPPS INSTITUTION
OF OCEANOGRAPHY

1976

# UCSD

UNIVERSITY OF CALIFORNIA, SAN DIEGO

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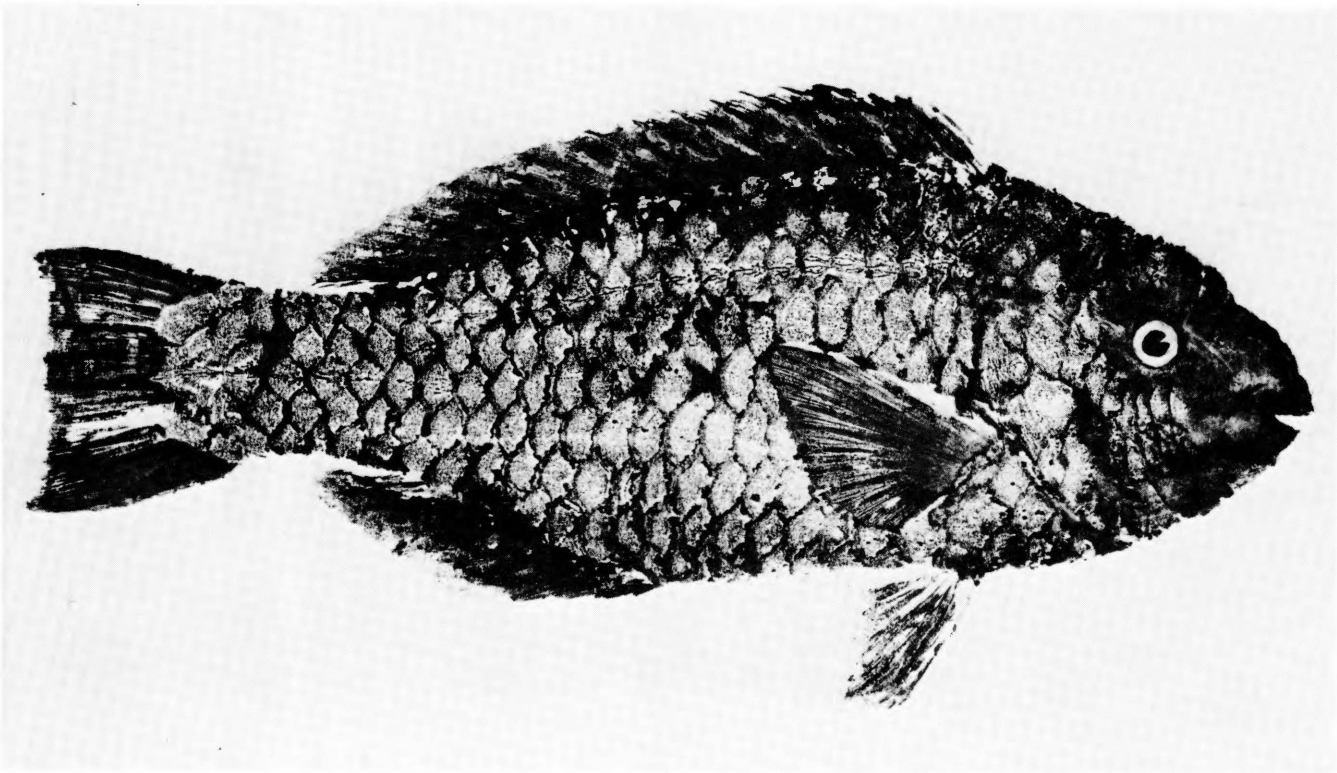
Cover photo: R/V *Thomas Washington,* between ropes, with R/V *Melville* at Nimitz Marine Facility pier, steams across San Diego Bay to fuel dock at the beginning of Indopac Expedition (Indo-Pacific) in the spring of 1976. Photo by Jackie Janke.

Layout and design/Eric Baker.



*Heidi Hahn*

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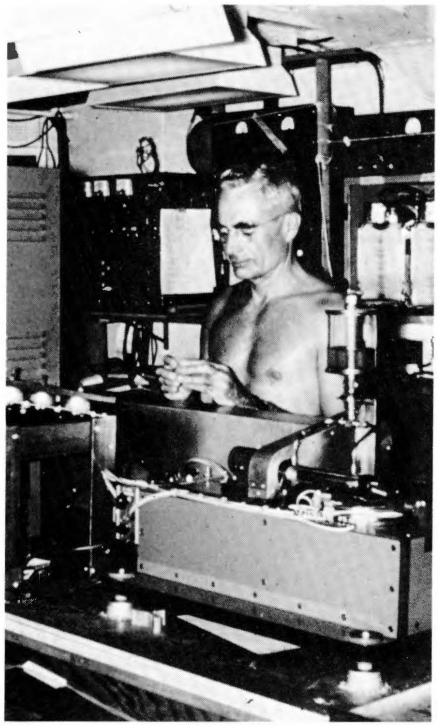
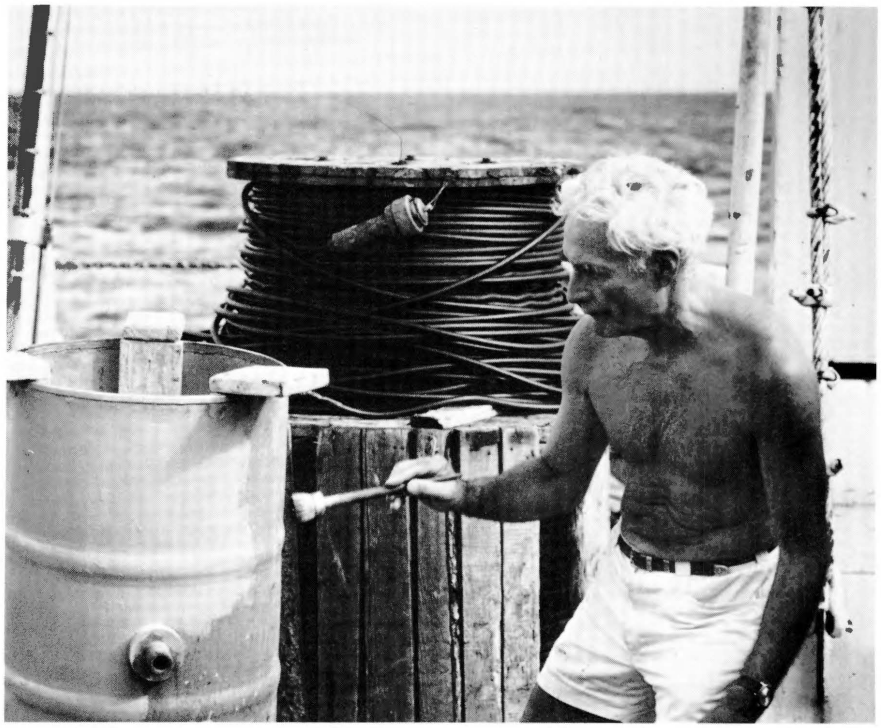




*Vic Vacquier makes magnetic measurements on ocean sediments in laboratory of R/V* Argo *during her six-months maiden voyage for the institution in 1960-61, on Monsoon Expedition. Ship was sailing the Indian Ocean when photograph was taken. Then, in 1972, Vic spent 33 days aboard USSR research vessel* Dmitri Mendeleev *as she worked in the western Pacific. In his usual at-sea attire, Vic contributes to international amity by painting steel drum used by a Russian biologist for her plankton catch.*

# DEDICATION

He's participated in many of Scripps's long expeditions in the Pacific, and spent 33 days at sea aboard USSR research vessel *Dmitri Mendeleev.*

On land, he's measured heat flow in lakes in interesting and exotic tectonic situations such as east African rifts (Lake Malawi) and the high Andes (Lake Titicaca).

More recently he developed a technique for making heat-flow measurements from standard oil-well survey data that he tested in the oil fields of Brazil. And he is preparing to test this new method of measuring heat flow in Indonesia.

He's been largely responsible for delineating the still-puzzling low heat flow of the Guatemala Basin.

It would almost seem that peripatetic Victor Vacquier was predestined for widespread travels such as these. He was born in Leningrad in 1907, and after three years in France, came to the United States in 1923.

The University of Wisconsin claimed his undergraduate and graduate days, which were followed by ten years in private industry. There he helped develop new instrumentation and techniques for geophysical prospecting. In fact, it was with the Gulf Research and Development Company, in the thirties, that he patented the fluxgate magnetometer along with its application to the successful magnetic airborne detection (MAD) of submerged submarines.

With his innate ability to make new instrumentation work in remote and difficult environments, it is hardly surprising that, after joining Scripps in 1957, he was instrumental in developing a simplified form of the proton precession magnetometer for mapping the total magnetic field at sea.

Utilizing this instrumentation and working in the early 1960s with his Scripps colleagues, Arthur Raff and Robert Warren, Vic was able to extend the remarkable magnetic anomaly lineations off the west coast of the United States, originally discovered by Raff and Ronald Mason, and establish the very large fault displacements (as great as 1,400 km in some places) of the mapped anomaly patterns. These data were the forerunners of the concepts of sea-floor spreading and plate tectonics.

Vic also extended his interest in the electrical conductivity structure in the earth with electromagnetic induction studies. Together with Ulrich Schmucker and Antony White, he employed profiles of temporary magnetometer stations across the southwestern United States and Mexico to delineate the conductivity structure of that part of the continent. And with John Greenhouse, he employed recording ocean-bottom magnetometers to extend the profiles out to sea. These studies complemented related investigations in the same region carried out by Charles Cox and Jean Filloux, and constitute the only such study thus far across the fundamental transition from continent to ocean basin.

The success of this geophysicist's research has brought accolades from his peers. In 1960, the Franklin Institute awarded Vic its John Price Wetherill Medal; the American Miscellaneous Society gave him its Albatross Award in 1964; the American Geophysical Union presented him its John Adam Fleming Medal in 1973, and in 1975 the Society of Exploration Geophysicists presented him its highly prized Medal Award.

Even his latest hobby of amateur astronomy grew out of what has been described as Vic's intuitive feeling for the most significant and easily accomplished projects. Example: his attempt to measure active fault displacement across the Gulf of California by optical methods. Although no displacement was measured in a period of two years, he did establish a simple, inexpensive method for measuring a fundamental parameter of plate tectonics.

*Dr. Walter H. Munk (at left) and Dr. Cheng Kwei Tseng meet for first time in 30 years during visit to campus in October by 12 scientists from the People's Republic of China. Dr. Tseng was a research associate at Scripps between 1943 and 1946. Deputy Director Merdinger is at right; between Drs. Munk and Tseng are Dr. Ching-yi Liu (foreground) and Yung-Hang Chu. Visiting scientists were briefed by faculty and research staff and were guests of the institution at an alfresco dinner held in library patio.*
*Photo by Tim Wilson, courtesy of San Diego* Evening Tribune.

# INTRODUCTION

As always, I can report another busy and hectic year, perhaps too busy and too hectic.

The year started rather rapidly with the long-awaited visit of His Majesty, the Emperor of Japan. It was shortly followed by another exciting visit, this one by a distinguished group of scientists and engineers from the People's Republic of China.

The latter visit had its human aspect because the deputy chairman of the group, Dr. Cheng Kwei Tseng, had worked at Scripps between 1943 and 1946. It was very heartwarming to realize that essentially all of the senior people he had known and worked with were still at the institution, and some not even near retirement.

The generally negative features we face are the increasingly complex array of problems thrust upon the institution by the federal government and the State of California, not only in content, but also in administrative form. I am beginning to sense a feeling of frustration that could lead to a revolution on the part of the working scientists.

On the positive side, the growing interest and support of the State of California in the work of the institution is clear. The nearly completed library and marine biology building are a visible indication of this interest, and there is no reason to believe that other needed buildings will not be soon forthcoming.

The most exciting development this year, which had a bit of theater, was the progress of the research vessel *Alexander Agassiz* replacement through the governor's budget and the legislature until final approval. The proposed vessel should go out to bid in midfall of 1976.

On the federal scene, it is becoming evident that support for ocean research is breaking out of its current plateau, with much indication of positive support from even new quarters.

The reader of this report will observe that members of the institution have received, as usual, their fair share of awards during the year. Particular note should be made of the fact that Walter Munk received three of the most highly coveted awards — not only in the one year, but they were announced within a period of six weeks.

Finally, and with great regret, we record the passing of Helen Raitt, known to many of us and a long-time friend of the institution. She wrote the book, *Exploring the Deep Pacific,* an account of Capricorn Expedition, in which she participated, and coauthored the institution's first definitive history, *Scripps Institution of Oceanography: The First Fifty Years.*

William A. Nierenberg, Director
*Scripps Institution of Oceanography*

*R/V* Dolphin

*R/V* Alpha Helix

# SEAGOING OPERATIONS

## *Nimitz Marine Facility and the Fleet*

Fiscal 1975-1976 opened with R/V *Melville* in caretaker status and R/V *Thomas Washington* undergoing extensive modifications and her biennial overhaul. R/V *Alexander Agassiz,* R/V *Alpha Helix,* R/V *Ellen B. Scripps,* R/V *Dolphin,* R/P FLIP and R/P ORB were operational. In January 1976 *Thomas Washington* and *Melville* were readied for extended cruises. The fleet spent a total of 1,074 days at sea and traveled 100,427 nautical miles.

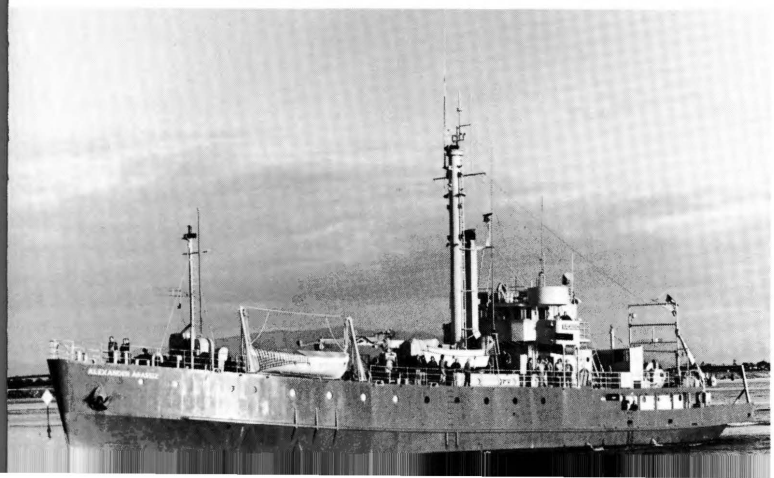
Lack of funds kept R/V *Melville* near the Nimitz Marine Facility dock until March when the ship was overhauled and made a short Deep-Tow trip with Dr. Fred N. Spiess as scientist-in-charge. On April 29 *Melville* departed San Diego on Leg I of the Pleiades Expedition with Drs. Peter F. Lonsdale and Raymond F. Weiss as scientists-in-charge. This expedition focused on studies of the geology and geochemistry of the sea floor in the East Pacific Rise and Galápagos Islands area. Leg II of Pleiades started from Balboa, Canal Zone, with Drs. Richard P. Von Herzen, Woods Hole Oceanographic Institution, Massachusetts, and John B. Corliss, Oregon State University, Corvallis, conducting heat-flow surveys and deploying ocean bottom seismographs. *Melville* spent a total of 99 days at sea and steamed 6,395 nautical miles, prior to the end of June.

R/V *Thomas Washington* returned to San Diego from Eurydice Expedition in July 1975. She remained in the area, undergoing extensive modifications and overhaul until the first of the year with the exception of two days towing R/P FLIP in October. In Jaunary, *Thomas Washington* departed on Deep Sonde Expedition, with Dr. LeRoy M. Dorman as scientist-in-charge. In March she sailed on Leg I of Indopac Expedition, with Dr. Kern E. Kenyon as scientific leader. Indopac investigated the geology and physical oceanography of the marginal basins of the Western Pacific and Southeast Asia. Several cooperative arrangements and international programs were involved. Water sampling and bottom sampling, as well as magnetometer measurements, were conducted. Joseph L. Reid joined *Thomas Washington* in Yokohama as scientific leader for Legs II and III. His program consisted of a study of the circulation of the Philippine Sea and Western Pacific Ocean. Dr. James W. Hawkins met the ship in Guam and became the scientific leader for Leg IV. The objective of this leg was to survey and sample the inner wall of the Yap and Palau trenches. The ship logged 171 days at sea and steamed 26,911 nautical miles.

R/V *Alexander Agassiz* opened the year on a CalCOFI (California Cooperative Oceanic Fisheries Investigations) cruise off Baja California, Mexico. This operation was followed by a series of short trips in which geological and camera studies, fish sampling, mid-water trawls, and student instruction were conducted. A second CalCOFI cruise took place in October. There followed a series of Southern California Base Line sampling operations and a California Current cruise as well as plankton studies on the Southern California Bight. *Alexander Agassiz* logged 19,504 nautical miles and 178 days at sea.

Fiscal 1976 found R/V *Alpha Helix* on East Asian Expedi-

*R/V* Alexander Agassiz



*R/P ORB*

*R/V* Thomas Washington

*R/V* Ellen B. Scripps

tion Phase II studying the comparative physiology and ecology of the animals of Brunei. Dr. Brian K. McNab, University of Florida, Gainesville, was scientist-in-charge. The East Asian Expedition Phase III was led by Dr. William A. Dunson, Pennsylvania State University, University Park, and Phase IV was headed by Dr. James R. Redmond, Iowa State University, Ames. Both phases of the expedition were carried out in the central and southern Philippines, and emphasized examination of marine snakes and chambered nautilus, respectively. The ship returned to San Diego in December, after evading Typhoon June, one of the most severe in recent history. With the overhaul completed in January, *Alpha Helix* was readied for her upcoming expeditions. On Joint Two Expedition, en route to the Amazon River, a series of studies was made off Peru. These included the analysis of ocean fronts, with Dr. Ted Packard, Bigelow Laboratory, West Boothbay Harbor, Maine, as scientist-in-charge. Current meter reading and meteorological studies were conducted, under Drs. Richard Dugdale of Bigelow Laboratory and Robert L. Smith, Oregon State University. Phytoplankton studies, oblique net tows, and bottle casts were made, with Dr. Dugdale in charge, and the study of phytoplankton ecology was carried out, with Dr. Richard T. Barber, Duke University, North Carolina, as chief scientist. In May *Alpha Helix* transited the Panama Canal to begin Amazon Expedition, Phase I, Leg I, with Dr. John M. Edmond, Massachusetts Institute of Technology, Cambridge, in charge. He conducted a geochemical survey of the Amazon River and its major tributaries taking the ship inland as far as Iquitos, Peru. *Alpha Helix* logged 285 days at sea and steamed 27,528 nautical miles.

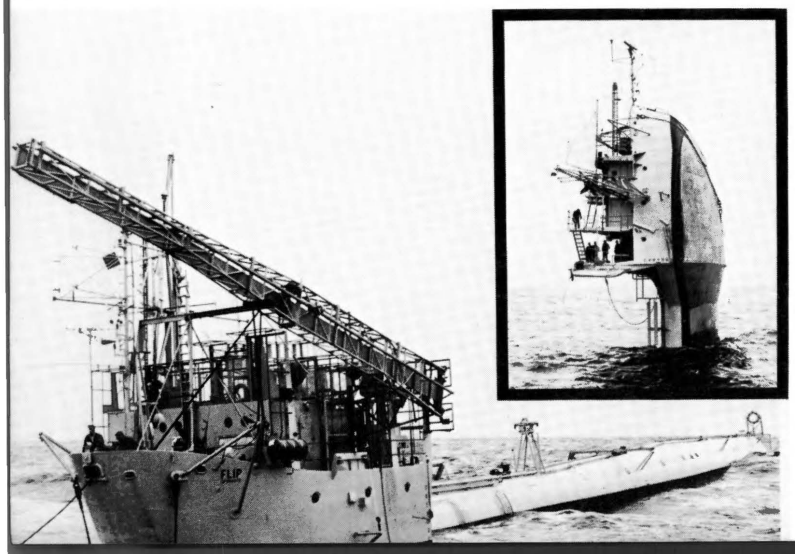
During this fiscal year, R/V *Ellen B. Scripps* completed 43 trips that variously involved instrument calibrations and checks, water-structure studies, student cruises, hydrophone and current-meter tests, towing ORB, environmental studies, Extremely Low Frequency (ELF) tests, joint acoustics transmission with *Alexander Agassiz* and the Canadian Forces Auxiliary Vessel *Endeavour* from Esquimalt, British Columbia, deployment and recovery of seismic instruments, and heat-flow tests. She logged 10,361 nautical miles in 137 days at sea.

R/V *Dolphin* made two extended cruises, one to Guadalupe Island, off Mexico, and the other to the Gulf of California. Her local use included current studies in submarine canyons, two-way acoustic transmission experiments, and flora investigations in the vicinity of Santa Catalina and San Clemente islands, off California. While she was in the Gulf of California, experiments were conducted on the thermophysiology of young birds and marine biology and chemistry, under Dr. William Dawson, University of Michigan, Ann Arbor. The ship spent a total of 120 days at sea and logged 7,812 nautical miles. *Dolphin* was placed out of service in June.

R/P FLIP made four cruises during the year: one, a tow-by demonstration for His Highness, Hirohito, Emperor of Japan, off Scripps Pier, and the others for acoustical studies conducted by Dr. Frederick H. Fisher. FLIP was towed 1,066 nautical miles and spent 33 days at sea.

R/P ORB was towed into position on five occasions to support studies of acoustic volume reverberation in scattering layers, aided the Naval Undersea Center, of San Diego, in the evaluation of a Hydro Acoustics, Inc., contract, and

*R/P FLIP*



*R/V* Melville

*George L. Hammond (left) and Jack W. McDonald cast off R/V* Thomas Washington's *ropes as she leaves Nimitz Marine Facility pier in the spring of 1976 to explore the marginal ocean basins of the western Pacific and Southeast Asia during Indopac Expedition.*

*Jackie Janke*

made acoustic scattering and high-frequency reverberations studies. ORB spent 51 days off shore and was towed 850 nautical miles.

## *Anniversary Reunion*

The twenty-fifth and twenty-third anniversaries of Scripps's first two major Pacific Expeditions, Mid-Pac and Capricorn, respectively, were celebrated in San Diego on August 17, 1975, with a reunion dinner of expedition participants.

Among the photographs and other memorabilia shared by the former shipmates were relics from America's first thermonuclear tests in the South Pacific, which many of the scientists had observed during Capricorn at the request of the federal government.

Both expeditions required the teamwork of two ships for ocean-floor studies. On Operation Mid-Pac, in 1950, 85 crew members and 30 scientists served on board Scripps's R/V *Horizon,* a 143-ft. converted Navy tug, and the Naval Electronics Laboratory's 220-ft. USS EPCE (R)-857, later named the USS *Marysville,* for a joint UC-U.S. Navy effort.

For Capricorn, in 1952-53, *Horizon* teamed up with Scripps's *Spencer F. Baird,* another 143-ft. converted tug, which was equipped with a new winch and 12,192 m of tapered wire for its primary mission: to explore the Tonga Trench. This deep-sea feature, a chasm in places deeper than seven superposed Grand Canyons, extends for more than 16,600 km in a line between New Zealand and Samoa.

Mid-Pac and Capricorn yielded many discoveries, including the first evidence supporting what now is generally accepted as sea-floor spreading and the more general hypothesis of plate tectonics; the location of an enormous

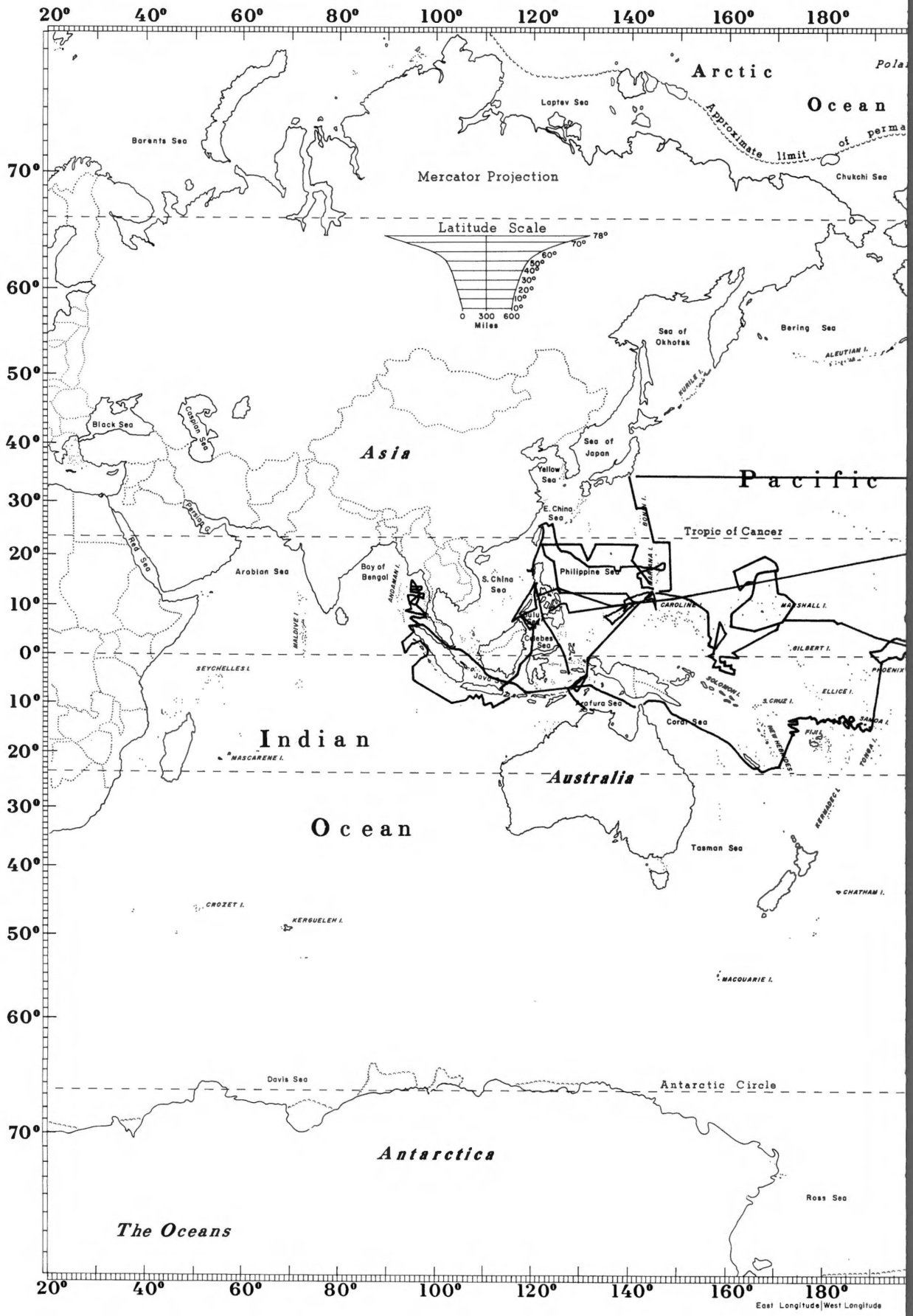
*Operation Mid-Pac participants attending anniversary dinner were (left to right), Dr. Russell W. Raitt, Edward S. Barr, Daniel K. Gibson, Dr. Edwin L. Hamilton, James M. Snodgrass, Dr. H. William Menard, Dr. Roger R. Revelle, Capt. James L. Faughn, Robert P. Huffer, and Jeffery D. Frautschy.*

*From Capricorn Expedition came these reunion participants (left to right), Edward S. Barr, Dr. Robert L. Fisher, Dr. H. William Menard, Dr. William R. Riedel, Dr. Gustaf Arrhenius, Dr. Walter H. Munk, Daniel K. Gibson, Dr. Edwin L. Hamilton, Dr. Roger R. Revelle, the late Helen Raitt, Dr. Norman J. Holter, Dr. Ronald G. Mason, Dr. Robert B. Livingston, Samuel Scripps, Dr. Theodore R. Folsom, Warren W. Beckwith, and Dr. Russell W. Raitt. Kneeling is Alan Jones.*

underwater mountain range in the central Pacific, extensive manganese dioxide deposits near Bikini Atoll, ancient deep-sea bacteria that were later revived, a 1,600-km-long submarine cliff perpendicular to the northern California coast, and explorations of what may be the tallest mountain in the world, Capricorn Guyot, and the deepest point in the Southern Hemisphere, Horizon Deep, which are both in the Tonga Trench area.

### *Ships Gather Data*

Mid-Pac was described as the first large-scale American scientific exploration of the deep Pacific in more than two decades. The two ships traveled a total of 27,000 nautical miles during a three-months expedition that yielded data disproving some long-held ideas about the Pacific and verifying others, according to Dr. Roger R. Revelle, who became


Arctic
Ocean
Pola
Approximate limit of perma
Laptev Sea
Barents Sea
Chukchi Sea
Mercator Projection
Latitude Scale
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60°
50°
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30°
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Miles
Sea of Okhotsk
Bering Sea
ALEUTIAN I.
KURILE I.
Black Sea
Caspian Sea
Asia
Sea of Japan
Yellow Sea
E. China Sea
Pacific
BONIN I.
Tropic of Cancer
Persian G.
Red Sea
Arabian Sea
Bay of Bengal
ANDAMAN I.
S. China Sea
Philippine Sea
MARIANA I.
CAROLINE
MARSHALL I.
MALDIVE I.
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Celebes Sea
GILBERT I.
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S. CRUZ I.
Arafura Sea
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NEW HEBRIDES I.
TONGA I.
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KERMADEC I.
Tasman Sea
CHATHAM I.
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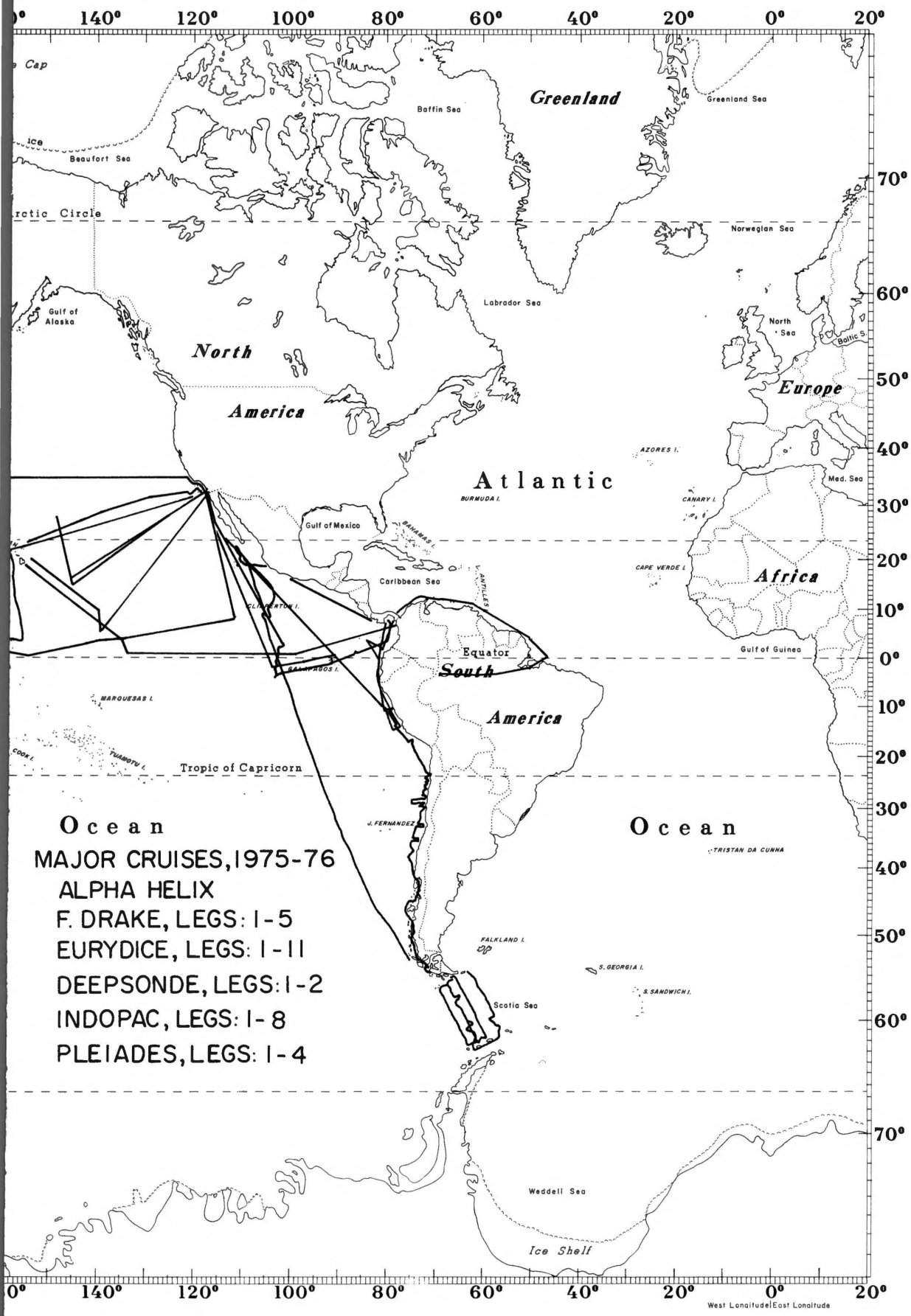
MACQUARIE I.
Davis Sea
Antarctic Circle
Antarctica
Ross Sea
The Oceans
East Longitude | West Longitude




MAJOR CRUISES, 1975-76
ALPHA HELIX
F. DRAKE, LEGS: 1-5
EURYDICE, LEGS: 1-11
DEEPSONDE, LEGS: 1-2
INDOPAC, LEGS: 1-8
PLEIADES, LEGS: 1-4

*Reminiscing as they read a yellowed newspaper clipping, one of the many memorabilia displayed at joint expedition anniversary dinner of participants in Operation Mid-Pac and Capricorn Expedition, are (from left), Dr. H. William Menard, professor of geophysics; the late Helen Raitt; Dr. Roger R. Revelle, director of Scripps, 1951-64, who led both expeditions; and Dr. Walter H. Munk, professor of geophysics. Mid-Pac took place in 1951; Capricorn in 1952-53. Helen Raitt, who passed away in March 1976, was the only woman aboard Capricorn.*

director of Scripps in 1951 and who led both expeditions.

Dr. Revelle is now director emeritus of both Scripps and the Center for Population Studies, Harvard University, Cambridge, Massachusetts. He is a professor recalled to active duty at UC San Diego and continues to teach at Harvard, spending one semester a year at each institution.

The departures of *Horizon* and *Spencer F. Baird* from San Diego for Capricorn were without fanfare, since the trip included participation in the military's Operation Ivy, the first thermonuclear tests at Eniwetok Atoll, in the South Pacific in 1952.

Scripps staff designed and built special equipment for making observations during the tests. They later received a formal commendation from Admiral C. M. Bolster, then Chief of Naval Research, for the performance of "difficult and dangerous tasks . . . adding important data to our growing knowledge of weapons effects."

Several of the 45 scientists and many of the 42 crew members who participated in Capricorn had also served on Mid-Pac. *Spencer F. Baird's* 17,400 nautical mile cruise took about four months and *Horizon's* 22,300 nautical mile trip lasted nearly five months.

Dr. Revelle, who had been in charge of the Navy's oceanographic research during World War II, said that before these "voyages of discovery," scientists were more familiar with the North Pole and the jungles of South America than they were with the ocean, which covers more than two-thirds of the earth's surface.

A key factor in this ignorance was inadequate equipment. In 1956 Dr. Revelle said, ". . . until the last few years, the methods for penetrating beneath the sea surface were inadequate to give more than a vague, and in many respects, a quite erroneous, picture."

## *New Equipment Developed*

But, during World War II, the U.S. Government's interest in oceanography and exploration of the Pacific had, of necessity, increased. New equipment for subsurface research that had been developed for submarine warfare would now enable man to study the vast frontier of the Pacific Ocean, about which comparatively little was known.

Armed with then recently developed electronic equipment and the latest scientific gadgets available, members of these expeditions, like their colleagues on the other coasts, launched their assault on the unknown.

Dr. Revelle's comment at the end of Mid-Pac was: "We've got a lot of interesting information on the Pacific Ocean that may turn out to be the richest oceanographic haul ever taken — data that may give us the answers to the origin of the earth itself.

"At any rate, we do know this: the Pacific is a vast, watery frontier and . . . we've only scratched the Pacific's bottom!"

Since Mid-Pac and Capricorn expeditions, Scripps ships, which now number six, have steamed approximately four million nautical miles in oceanographic research. The institution's data files now contain detailed information about much of the ocean's topography, chemistry, and animal life, and thousands of publications have been written.

## *Expedition Described*

On July 27, 1950, *Horizon* and the Navy's USS EPCE (R)-857 departed San Diego. The joint University of California/U.S. Navy expedition was sponsored by UC's Institute of Geophysics, the Office of Naval Research, and the U.S. Navy's Bureau of Ships, and carried out by Scripps and the U.S. Naval Electronics Laboratory at San Diego.

Meteorologists, geologists, chemists, and biologists from Scripps, UC Los Angeles, University of Southern California, Stanford University, the U.S. Geological Survey, and the U.S. Navy served on Mid-Pac. Most of them were from Scripps or were former Scripps graduate students and professors, or underwater experts who had worked on Navy submarine problems during World War II. Some of these persons are currently on Scripps's staff.

Scientists had previously believed that the floor of the Pacific had remained relatively stable for hundreds of millions of years. But the mass of evidence brought back by Mid-Pac scientists showed that it had been evolving for millions of years and there had been changes of up to thousands of meters in depth.

Among the expedition's other findings were:

— a 1,600-km-long underwater mountain range in the central Pacific that is 160 km wide, up to 4.2 km in height, and 1.6 km beneath the sea surface. The submerged mountain range, named "Mid-Pacifc Mountains," stretches all the way from Wake Island to Necker Island near the Hawaiian group. The Pacific Ocean floor was previously thought to be shaped like a large, muddy bowl with little geologic activity. Instead, the vast floor was found to be as rugged as the U.S. continent, with mountains, valleys, plains, buttes, peaks, canyons, and cliffs. Most of the seamounts were flat on top, as if they had been eroded by wave action in shallow water and then sunk below the surface. Extinct reef-building corals and sea-urchin fossils were dredged from atop a seamount that had sunk to the 1,800-m level.

  Scientists believe flat-topped seamounts (termed guyots) in this area sank during Middle Cretaceous to below the zone of coral-reef growth and then finally to their present depth. These seamounts furnished evidence for a deep Cretaceous Pacific Ocean, refuting the hypothesis that animals could have crossed the Pacific on now-submerged, transoceanic continents, but suggesting the possibility of "island stepping stones." These findings also confirmed

Darwin's theory of subsidence with regard to the formation of coral reefs growing on sinking volcanoes. Dr. Revelle said the coral atolls Kwajalein and Bikini are the largest structures ever made by living creatures. He said, "In comparison, the pyramids of Egypt and the Empire State Building are microscopic."

— seismic refraction studies revealed that the central Pacific's sediment layer was only about 100 m thick instead of the previous estimate of 3,000 m, again supporting the concept of a young ocean floor, one of the tenets of the "new" plate tectonics. Such seismic measurements also demonstrated the relative thickness and uniformity of the earth's crust in oceanic areas, features profoundly different from those under the continental areas. Mid-Pac, and later Capricorn, carried these measurements out on a geographic scale seldom approached since that time.

— first use of a heat-flow measuring device, developed at Scripps, revealed that heat flowing through the oceans floor was as great as that under the continents. Dr. Revelle said, "This was an indication that the mantle must be slowly churning."

— submarine cliff extending more than 1,600 km seaward from the earlier-known Mendocino Escarpment off the northern California coast.

— bacteria from the deep sea that may have "slept" for millions of years were revived in a culture medium. Dr. Revelle had suggested then that these bacteria, which had been buried under 6 m of mud, were in a state of suspended animation in nature's "deep freeze," since little food exists at that depth.

— extensive manganese dioxide deposits, with an estimated 100 million tons on Sylvania Seamount, near Bikini Atoll, and photographs revealing that the seamount surface was rippled and swept by deep currents.

### *New Tools Aid Ocean Exploration*

Many discoveries were made possible by the use of new tools for ocean exploration. Some of these were the recording echo sounder, which traces the bottom configuration of the ocean without stopping a ship; a complex electronic thermometer, for measuring the temperature gradients of deep bottom mud; a new type of dredge for scooping rocks off the ocean floor; a remotely operating, underwater camera, developed at the U.S. Naval Electronics Laboratory, for obtaining flash pictures at oceanic depths; a new technique for pulling long cores of mud from the bottom of the sea; a chemical analytical process for counting bacteria in bottom muds and measuring dissolved chemical substances, and a new method of ocean-floor analysis by seismic refraction.

The seismic refraction technique requires the teamwork of two ships. One ship sets off a high explosive charge and the other detects the seismic waves after they have traveled through the rocks beneath the ocean. During Mid-Pac, the two ships were sometimes as far as 128 km apart when this method was used, and a total of 15,876 kg of TNT — some 1,600 separate shots — were exploded during the voyage.

Mid-Pac scientists also assisted the Navy's air-sea rescue system by regularly exploding four-pound SOFAR (*So*und *F*ixing *a*nd *R*anging) bombs to set a 5,600-km-record of long-range sound propagation. This work was later named "the shot heard 'round the Pacific."

The two ships, which have been described as being not much larger than Magellan's *Trinidada* and *Vittorio,* returned to San Diego in November 1950, with a booty of statistic-filled notebooks, newly drawn charts and graphs, tubes of cored mud from the sea floor, odd pieces of rock, coral, and fossilized shells; hundreds of bottles of seawater and preserved fish, and a variety of bent and battered gear.

### *Expedition Results Listed*

To further the investigation of the Pacific sea floor, Capricorn Expedition, also funded primarily by the Navy, was launched in the fall of 1952. After completion of the thermonuclear tests at Eniwetok Atoll, the ships proceeded to the Tonga area to map the ocean floor.

Research in the Tonga Trench region yielded data later used to develop and buttress the sea-floor-spreading and plate tectonics concepts. Almost no sediment was found at the V-shaped trench, an indication that either the trench was very new or that material was folded into the earth as fast as it was accumulated, said Dr. Revelle.

Exploration of Capricorn Guyot, just offshore of Tonga Trench, showed that its summit was tilted slightly toward the trench, a factor that directly suggests the moving of its foundation toward the trench.

Soundings of the Tonga Trench by *Horizon* were the deepest ever taken in the Southern Hemisphere and established that the trench is second only to the Mariana Trench, near Guam, in depth.

Other evidence of crustal, or mantle, movement was obtained by comparing heat-flow measurements of the sediments in the East Pacific Rise with those on the normal sea floor near the trenches. Temperatures were higher at the rise, and this, Dr. Revelle said, was an indication that the material was rising at the ridge and sinking at the trenches.

Another "first" was the use of aqua-lung divers for the investigation of undersea volcanoes. One of the areas studied was shark-infested Falcon Shoal, a volcanic island in the Tonga group that has been above and below the ocean's surface several times in the last hundred years.

Dr. Revelle said that during the expedition scientists conducted a variety of studies, including electric currents in the atmosphere, with instruments sent nearly 16 km above the sea surface; wave-motion, magnetic profiling, hydrographic casts, and plankton tows. But, he said most of the researchers were marine geologists and geophysicists eager to learn the history of the ocean throughout geologic time.

The track of the expedition was across the Pacific to the Hawaiian Islands, on to the Marshall Islands area, then to the Fiji Islands, over the Tonga Deep to Tahiti in the Society group and the Marquesas Islands, on toward Easter Island and the East Pacific Rise, and north to San Diego.

# MAJOR EXPEDITIONS

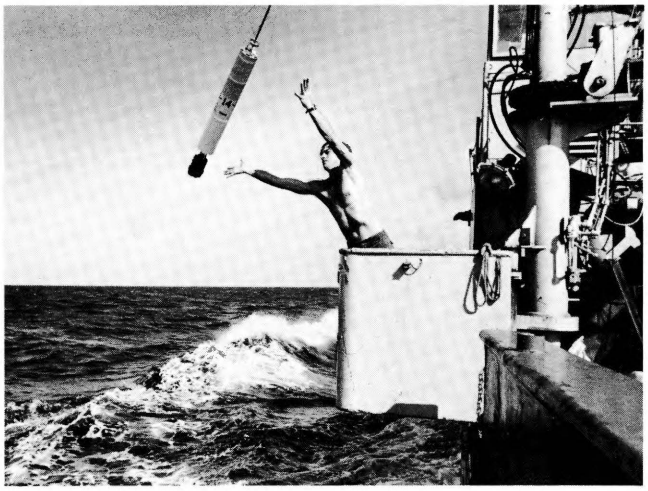
## *Eurydice Expedition*

When R/V *Thomas Washington* returned to her Nimitz Marine Facility berth in San Diego on July 18, 1975, she concluded an extended cruise into the Pacific and Indian oceans.

The ship left San Diego in September 1974, and logged some 43,000 nautical miles during the 11 legs of the Eurydice Expedition. During the expedition geological, geophysical, biological, and physical oceanographic research was conducted.

Expedition coordinator was Dr. Edward L. Winterer. He also served as chief scientist for two of the 11 legs of the cruise, including the final leg that brought the ship in to port from Majuro, Marshall Islands.

Much of the data obtained during the cruise were based on



*Eurydice Expedition involved many types of oceanographic research, some of which are illustrated here. Aboard R/V* Thomas Washington *(upper left) are (left to right) Thomas J. Walsh, Robert C. Wilson, graduate student Kathleen Crane, George D. Wilson, Dr. Wolfgang H. Berger, and Dr. Peter H. Roth. They are disassembling core barrels to obtain sediment brought up from the sea floor. Dr. Thomas C. Johnson (upper right) throws a sonobuoy used with other shipboard acoustic equipment to determine sediment sea-floor thickness. William M. (Skip) Jones, Jr., Oregon College of Education, Monmouth (middle left), carries oblique tow net after a long night's work of towing for surface material. Dr. Berger is in background. Standing by to remove pinger from wire (bottom left) are (left to right) Dr. Johnson, Jones, and George Wilson. Wilson is signaling winch operator to stop winch wire.*

*David L. Ripley*

geological studies conducted in the Central Pacific, around Fanning Island; on the slopes of the Ontong-Java Plateau, in the Nova-Canton Trough; along the northern border of the submarine Fiji Plateau; and in the Andaman Sea, in the Indian Ocean.

Scientists also worked in the moderately deep trenches off Sumatra and Java, did biological investigations in Indonesian waters and on the floor of the deepest part of the Philippine Trench, took geological samplings in the Challenger Deep within the Mariana Trench, and measured ocean currents in the Marshall Islands region.

Besides Dr. Winterer, other chief scientists on the expedition included Drs. Wolfgang H. Berger, Joseph R. Curray, Robert L. Fisher, George G. Shor, Jr., James W. Hawkins, Robert R. Hessler, and Peter H. Roth, and Joseph L. Reid; and Marcia Rottman, University of Colorado.

Captains Garrett S. Coleman and Albert Arsenault divided the ship master's duties. Of the 19 crew members returning with the ship, nine were on duty throughout the entire ten-and-a-half-months cruise.

## *East Asian Expedition*

More than 100 scientists from serveral nations participated in the 11-months East Asian Expedition, which ended November 13, 1975. The scientists conducted experimental biological and medical studies during the four phases of the expedition aboard R/V *Alpha Helix.*

Scientists on East Asian Expedition, Phase I, investigated the detection and generation of light by deep-sea organisms

*Scientists hold primitive spider from Malaysia (top left) and fruit bat from the Sultanate of Brunei (top right), studied during East Asian Expedition, Phase II in western Pacific. During Phase IV, in the southern Philippines (center left), fishermen bring a living nautilus* (Nautilus pompilius) *to scientists aboard* Alpha Helix. *The animals are captured at a depth of about 300 m in baited, bamboo, fish-type traps and then placed in shallow water for physiological observations. Diver (center right) is shown releasing nautilus for studies of animal's swimming behavior. On board ship (bottom right), scientists examine organs of a nautilus, and chief scientist Dr. James R. Redmond, Iowa State University, Ames (bottom left), conducts research on the animals in the ship's laboratory.*

*George T. Mitchell, Phase II*
*Walter W. Schneider, Phase IV*

and nocturnal mammals and insects in central Indonesia. The 85-day phase one was under the direction of Dr. G. Adrian Horridge, Australian National University, Canberra, and Dr. James F. Case, later replaced by Dr. James Childress, both from UC Santa Barbara. Among the creatures studied were the reef dwelling fishes *(Photoblepharon* and *Anomalops),* pony fish *(Gazza minuta),* coral colonies, lantern fish, grasshoppers, dragonflies, and many bioluminescent species.

The East Asian Expedition, Phase II, conducted in the Sultanate of Brunei on the northwest coast of Borneo, was led by Dr. Brian K. McNab, University of Florida, Gainesville. Comparative analyses of the ecology and behavioral responses of spiders, amphibians, fish, and mammals to the environment were made. Scientists also conducted medical surveys of the human inhabitants of Brunei, which showed hypertension, heart attacks, and ulcers are rare in these people.

*Alpha Helix* then moved to the central Philippines for East Asian Expedition, Phase III, led by Dr. William A. Dunson, Pennsylvania State University, University Park. This six-weeks phase emphasized studies of venomous sea snakes, corals, sponges, and reef fish and their predators.

East Asian Expedition, Phase IV, led by Dr. James R. Redmond, Iowa State University, Ames, focused on the *Nautilus pompilius.* Studies compared the nautilus to its modern descendants, squid and octopus.

En-route studies off Oahu, Hawaii, included the bioluminescence and genetics of mid-water organisms, by Dr. Richard Young, University of Hawaii, and analyses of parasites that live on mid-water and bottom fishes in the western Pacific region by Dr. Ju-shey Ho, California State University, Long Beach.

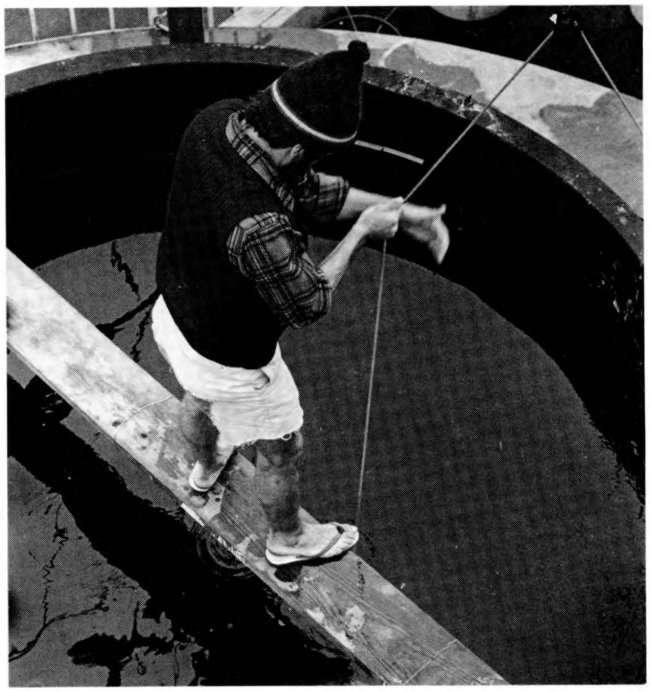
*Alpha Helix,* a national oceanographic facility sponsored by the National Science Foundation and operated by Scripps, was commanded by Wayne E. Bristol and Garrett S. Coleman during the expedition.

# GRADUATE DEPARTMENT

Graduate education at the Scripps Institution and its predecessors can be traced back to before the time the institution became a part of the University of California in 1912. Graduate degrees based on work done primarily at Scripps were awarded by UC Berkeley and UC Los Angeles until 1961, when UC San Diego became a degree-granting campus of the university.

In the early days of UC San Diego, graduate education was administered through the three departments at Scripps: oceanography, marine biology, and earth sciences. In 1967, these departments were merged into the present Graduate Department of the Scripps Institution of Oceanography. Curricular programs are offered within this department in applied ocean sciences, biological oceanography, geophysics, marine biology, marine chemistry, geological sciences, and physical oceanography. Each curricular group has some of its own special requirements for admission in addition to the requirements of the department as a whole.

Growth is often most vigorous in the rapid evolution of modern marine sciences at the boundaries of established disciplines, so that the interests of a given student, like those of many of the faculty, may fall somewhere between the limits of the curricular programs. It is the intent of the Scripps Graduate Department to provide maximum flexibility in meeting the specific interests of individual students.



*Graduate student David M. Checkley raises plankton net from Hydraulics Laboratory deep tank during food-chain-dynamics studies for his doctoral thesis. The insulated, refrigerated, cylindrical seawater tank is 10 m deep and 3 m in diameter, and is used for various physical and biological studies.*

*Dr. Elizabeth L. Venrick*

During the year covered by this report, the Graduate Department was chaired by Dr. Joseph R. Curray, until December 1975. Dr. Fred N. Spiess was appointed chairman in January 1976. Dr. Michael M. Mullin served as vice-chairman. The department includes 58 regular faculty members and four adjunct professors from the National Marine Fisheries Service. In addition, 15 members of the professional research staff voluntarily serve as lecturers in the department.

GRADUATE CURRICULAR PROGRAM. Each graduate student selects one of the seven curricular programs, which are described below and include the name of the faculty curricular-group coordinator. The Scripps Institution is largely a research institution. An important part of the educational program is the individual participation of each graduate student in some aspect of the research programs described elsewhere in this report.

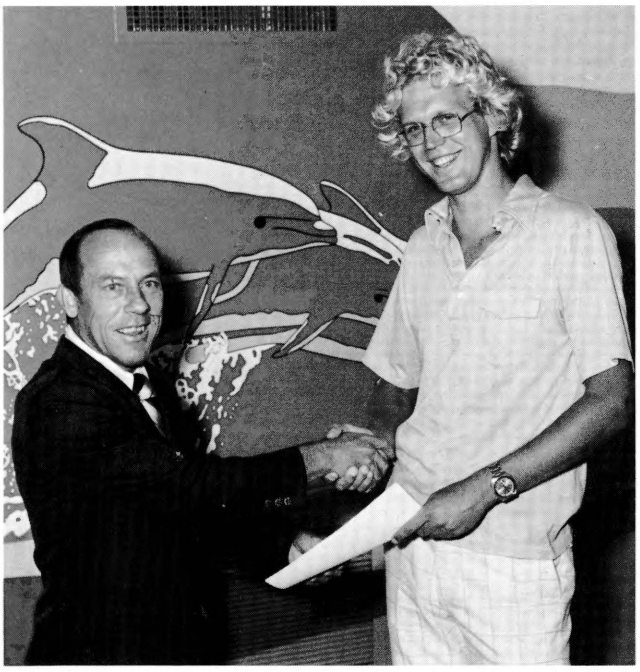
*Applied Ocean Sciences* (Dr. Clinton D. Winant). This curriculum is concerned with man's purposeful and useful intervention into the sea. Interdepartmental in nature, it combines the resources of the Graduate Department of Scripps and two engineering departments on the San Diego campus of the university: the Department of Applied Mechanics and Engineering Sciences and the Department of Applied Physics and Information Science. An attempt is made to produce modern engineers with a substantial training in oceanography and oceanographers with a significant ability in modern engineering. Instruction and research include structural, mechanical, material, electrical, and physiological problems operating within the ocean and the applied environmental science of the sea as well. Since

physical, chemical, geological, and biological aspects of the oceans and all forms of engineering may be involved, the curriculum provides maximum flexibility in meeting the needs of each individual student.

*Biological Oceanography* (Dr. Robert R. Hessler). Biological oceanographers are concerned with the interactions of populations of marine organisms with one another and with their physical-chemical environment. Research and education activities in this curriculum include studies of the factors influencing primary and secondary productivity and nutrient regeneration, food-chain dynamics, community ecology of benthic and pelagic forms, population dynamics, mathematical ecology, fisheries biology, taxonomy and zoogeography of oceanic organisms, and behavior as it affects distribution and sampling problems.

*Geophysics* (Dr. Robert L. Parker). This curriculum is designed to develop the ability of the physicist (theoretician or experimentalist) to contribute to man's understanding of the sea, the solid earth on which it moves, and the atmosphere with which it interacts. The program initially assists the student in assimilating current knowledge of the nature of the earth and in gaining mastery of field, laboratory, and mathematical techniques by which new information is being developed. With this basic background, the student is then expected to take part in the development of new insight into the problems of the structure of the earth and the nature of energy propagation and exchanges that take place within it.

*Marine Biology* (Dr. Ralph A. Lewin/Dr. George N. Somero). The Marine Biology Curriculum places particular emphasis on the manners in which marine organisms — animals, plants, and prokaryotes — are adapted to the physical, chemical, and biological conditions of the marine environment. Research and teaching encompass a wide range of biological disciplines, including behavior, neurobiology, developmental biology, and comparative physiology/biochemistry.



*Graduate student David M. Gardiner receives first $5,500 Carl L. Hubbs Sea World Fellowship from Sea World President David M. DeMotte. Gardiner is completing work toward his doctorate in marine biology. Dr. Hubbs is a professor emeritus of biology at Scripps and a member of Sea World's board of directors.*

*Sea World*

*Marine Chemistry* (Dr. Gustaf Arrhenius). Marine chemists are concerned with chemical processes operating within the marine environment: the oceans, the marine atmosphere, and the sea floor. The interactions of the components of seawater with the atmosphere, with sedimentary solid phases, and with plants and animals form the bases for research programs. These include investigations of the carbon system, natural products, chemical interaction between marine organisms, physical and inorganic chemistry of sediment-water systems, organic chemistry in the marine environment, distribution of noble gases in seawater, and effects of pollutants on the marine environment.

*Geological Sciences* (Dr. Edward L. Winterer). This curriculum emphasizes the application of observational, experimental, and theoretical methods of the basic sciences to the understanding of the solid earth and solar system and their relationship to the ocean and atmosphere. Principal subprograms at Scripps are marine geology, tectonics, sedimentology, micropaleontology, petrology, and geochemistry. Expedition work at sea and field work on land are emphasized as an essential complement to laboratory and theoretical studies.

*Physical Oceanography* (Dr. Robert S. Arthur). Studies in physical oceanography include the observation, analysis, and theoretical interpretation of the general circulation of ocean currents; the distribution and variation of properties of the ocean; the interchange of kinetic and thermal energy and materials across the ocean surface; the propagation of sound and light and other electromagnetic energy in the ocean; the properties and propagation of ocean waves; and the influence of surf on nearshore currents and the transport of sediments.

GRADUATE STUDENTS AND DEGREE RECIPIENTS. In the fall of 1975, 41 new students were admitted to graduate study. Of these, 10 were in marine biology, 6 in geological sciences, 3 in marine chemistry, 4 in biological oceanography, 7 in geophysics, 4 in physical oceanography and 7 in applied ocean sciences. Twenty-four were California residents, 13 were from out of state, and 4 were from foreign countries. Enrollment at the start of the 1975 academic year totaled 190 students. Five Master of Science degrees and 30 Doctor of Philosophy degrees were awarded by UC San Diego to students who completed advanced studies at Scripps during the academic year 1975-76. The names of degree recipients and the titles of doctoral dissertations are listed in Appendix E.

# RESEARCH ACTIVITIES

## *Deep Sea Drilling Project*

During the fiscal year 1976 another important milestone was passed by the Deep Sea Drilling Project (DSDP) with the conclusion of Phase III and the beginning of the International Phase of Ocean Drilling (IPOD). DSDP scientists have continued to make significant contributions to the fund of world knowledge while moving in an orderly fashion toward new and important goals.

The drilling vessel (D/V) *Glomar Challenger* underwent a major shipyard overhaul lasting the entire month of October,

during which new equipment and updated instrumentation were added to her already impressive inventory.

In keeping with the mood of IPOD, Memorandums of Agreement were signed with Japan, France, and the Federal Republic of Germany.* In each case the agreements are for a three-year period calling for individual contributions of one million dollars per year to the project. The United States' agreement with West Germany is the second such document between the two nations. Thus, there are now five participating foreign nations in DSDP; in addition to the aforementioned, they include the USSR and the United Kingdom.

In February 1976, Dr. Melvin N.A. Peterson, project manager and principal investigator, announced the appointment of Dr. David G. Moore as chief scientist succeeding Dr. N. Terence Edgar. Dr. Moore came to DSDP from the Naval Undersea Center in San Diego where he was a research marine geologist.

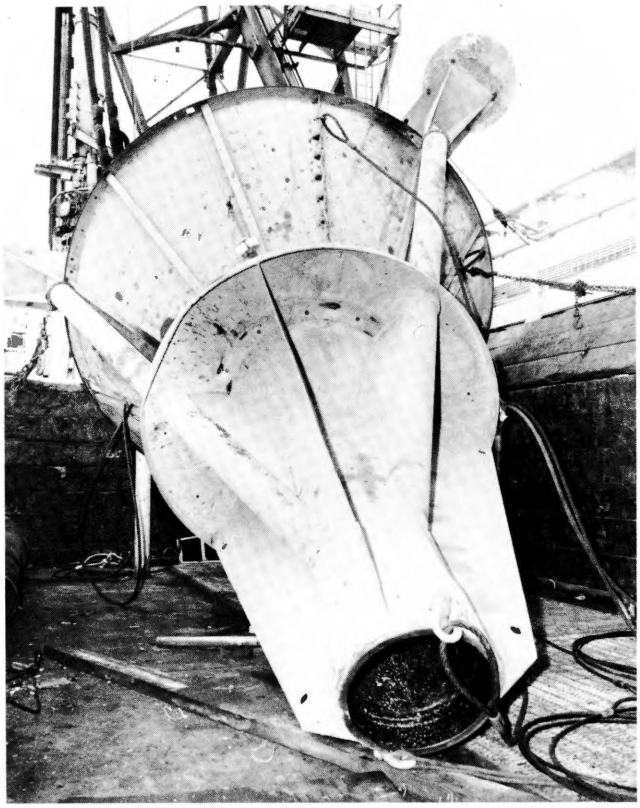
In fiscal 1976, *Glomar Challenger* traveled more than 20,000 nautical miles serving the needs of scientists on six cruises of approximately two months each. The shipboard scientific parties comprised representatives from nine foreign countries and, on three occasions, a French, a Russian, or an English scientist served as cochief scientist. During the year, 44 holes were drilled into the sea floor that resulted in the recovery of more than 1,000 cores. At one of these sites, in the Atlantic Ocean west of Portugal, a record penetration of 1,740 m into the sea floor was achieved. In the course of this record-setting drilling, the drill bit was replaced twice by using the DSDP-designed reentry system.

Early in the period (on Leg 43) two interesting discoveries were made at Site 384, drilled on the crest of a submarine ridge trending southwest from the southern edge of the Grand Banks. Shallow-water reef material showing evidence of rainwater solution was cored at depths of 4,133 to 4,236 m, making this by far the most deeply subsided former island so far discovered in ocean basins. Unlike the legendary Atlantis, however, this ridge began its long history of gradual sinking more than 105 million years ago. Volcanic rock recovered at the bottom of the hole indicates that the sunken island began life as an unusual portion of the Mid-Atlantic Ridge, emergent above sea level, perhaps like modern day Iceland.

After the former island had sunk about 2 km below sea level about 50-70 million years ago, it became covered by a steady "snowfall" of limey sediment from the ocean surface. This sediment contains the remains of myriads of microscopic organisms called nannoplankton and foraminifera. Although similar sediment presently covers vast areas of ocean floor, the section cored at Site 384 is unusual in that it contains a continuous record of microscopic fossils from the Late Cretaceous into the Tertiary. Gaps usually occur in the sedimentary record of the Tertiary on land as well as in the sea. Subsequent study of sediment recovered at this site may shed some light on the mysterious time about 65 million years ago when many species of marine animals, including the dinosaurs, became extinct.

During August and September, scientists on Leg 44 reported the discovery of drowned ancient reefs, Bahama-type tidal flats, and huge submarine mudflows. The specific object of Leg 44 was to increase man's knowledge of the western part of the Atlantic Ocean, especially near the continental margin off the east coast of the United States. The ancient reefs and carbonate flats are much like the banks surrounding the Bahama Islands today. The difference is that these reefs grew about 130 million years ago. They are now about 362 km east of St. Augustine, Florida, on the rim of the Blake Plateau

*The FRG Memorandum of Understanding was signed in Bonn on July 5, 1976.



*A reentry cone, assembled on D/V* Glomar Challenger, *is ready for use whenever scientists deem it necessary. Cone is picked up by crane, placed over port side in horizontal position, keel-hauled under the "moon pool," and sent to ocean bottom when initial drill string is lowered. Scientists can now use reentry technique at any drill site in any ocean of the world.*

*Deep Sea Drilling Project*

and in water nearly 2,700 m deep. The scientists had little doubt that the reef complex and associated lagoon-type limestones were deposited at or just a few centimeters below sea level. Moreover, the whole complex, at least 250 m thick, has been above sea level several times during its lifetime. Soil zones and evidence of solution by fresh water were found at several horizons. Sometime about 125 million years ago, the bank began to sink, the reef-building corals and algae died, and the whole area subsided to its present depth of several thousand meters.

The presence of the reef had been suspected from earlier geophysical profiling, but it remained for evidence from the core, taken by *Glomar Challenger,* to confirm the reef's presence and to permit the determination of its age and character.

Significant achievements of both scientifc and technical nature marked the two-part Leg 47 which spanned the time between March and May. During the first portion (Leg 47A), evidence of massive avalanching that has taken place at the edge of the African continent was uncovered, new clues regarding formation of the Sahara Desert were attained, and a record for drilling depth into the sea floor was established, to be later broken on Leg 47B. The latter was the previously mentioned penetration of 1,740 m that took place in a water depth of nearly 4,000 m.

While drilling off northwest Africa, Leg 47B investigators made significant discoveries concerning the birth and develop-

*Studying work-core half samples aboard D/V* Glomar Challenger *are Drs. Gerry A. Auffret (at left), of CNEXO (Centre National Pour l'Exploitation des Oceans), Brest, France, and Hideo Kagami, of the Ocean Research Institute, Tokyo, Japan. They were sedimentologists on Leg 48 of the Deep Sea Drilling Project.*

*Deep Sea Drilling Project*

ment of the North Atlantic Ocean and the separation of the European and North American land masses.

For the first time, extremely sensitive shipboard measurements were made to detect paleomagnetism of ocean-floor sediments that permitted DSDP scientists to discover past reversals of the earth's magnetic field. Such data aids in determining the age of the sediments and their rate of deposition, with an accuracy greater than that achieved by the study of the fossil record alone.

The increase of temperature with depth in the ocean's crust was explored with electronic instrument packages sent down in the drill string and pushed into the sediment and rock at the bottom of the bore hole. A temperature gradient of 4°C/100 m from the base of a thick pile of sediment on a continental margin is higher than once thought possible.

The 150 cores recovered in a continuous vertical sequence off Africa exposed a remarkably complex mixture of sediment types, some of which, prior to drilling, were thought to be completely foreign to the African type margin. If these rocks were viewed out of context somewhere high in a deformed mountain belt, geologists might have difficulty in deciphering their origin.

During the last leg of fiscal 1976, new drilling discoveries at the edge of the European continent revealed that swamplands fringed with coral reefs sank slowly 3 km beneath the Bay of Biscay and a great mountain range that once existed between Greenland and Europe also sank more than a kilometer below sea level. The sinking is probably related to the great forces that are responsible for continental drift. These latter discoveries were made by a multinational team of scientists on Leg 48 representing England, France, West Germany, Japan, USSR, and the United States.

In the northern Bay of Biscay, layers of 100-million-year-old, carbon-rich shale lying deep beneath the continental slope were recovered from an eroded, previously unknown, swamp area west of France and England. But corral reefs, now 2.4 to 3 km below the sea surface, show that the swamplands were fringed by a shallow, warm sea. The reefs continued to grow as the area foundered when Spain and a portion of Europe were separated some 130 million years ago. These new and important findings came from three holes drilled in water depths of 2.1 to 3.7 km using the dynamically positioned *Glomar Challenger.*

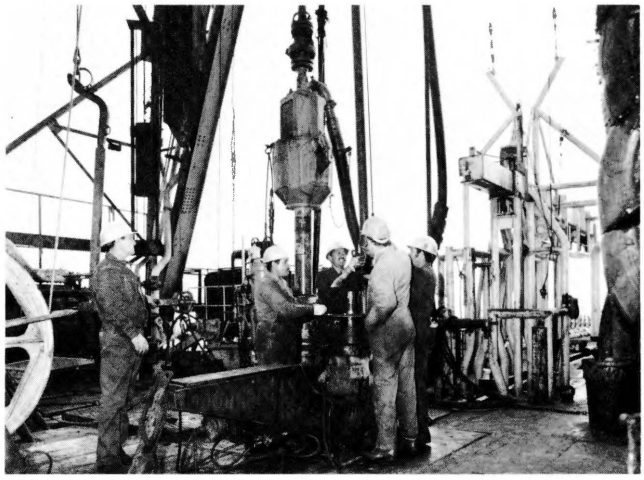
Four holes drilled in the mid-North Atlantic Ocean, west of tiny Rockall Island, yielded evidence that mountains and volcanoes once existed between Greenland and Europe. Here, great thermal forces, resulting in volcanic eruptions, pulled Greenland and Rockall apart some 60 million years ago. The remnants of these mountains now lie more than a kilometer beneath the sea.

In both the Biscay and Rockall areas, shipboard scientists discovered evidence of deep, cold-water currents that may have greatly changed the climate of the Atlantic Ocean.

For the first time in a marginal area, special radioactive sonic and electric tools used for exploration were sent down the drill pipe to log some of the properties of the sediments in the hole. A special mechanism designed to release the drill bit is an important new development for deep-sea well logging.

Scripps manages DSDP which is funded by the National Science Foundation through a contract with the University of California. The project is part of the foundation's Ocean Sediment Coring Program. The university subcontracts with Global Marine Inc., Los Angeles, to accomplish the actual drilling and coring by using Global's D/V *Glomar Challenger.*

Scientific advice is furnished to the project by panels from the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES). JOIDES members, including Scripps Institution of Oceanography, are the Lamont-Doherty Geological Observatory of Columbia University, New York; Rosenstiel School of Marine and Atmospheric Science, University of Miami, Florida; Department of Oceanography, University of Washington, Seattle; Woods Hole Oceanographic Institution, Massachusetts; USSR Academy of Sciences, Moscow; Bundesanstalt für Geowissenschaften und Rohstoffe, Federal Republic of Germany; Ocean Research Institute of the University of Tokyo, Japan; Hawaii Institute of Geophysics of the University of Hawaii; Oregon State University,



*During Deep Sea Drilling Project's Leg 48, Global Marine Inc. "roughnecks" lower Slumberger well-logging tool into drill pipe after drilling is completed at Hole 402A. On Leg 48, Holes 401, 402A, 403, 405, and 406 were logged, with a gamma-sonic caliper tool, a gamma-density neutron porosity tool, and a gamma-induction resistivity tool being utilized in the process. Logging program was implemented by successful use of a new bit-release mechanism that allows logging of single-bit holes without reentry.*

*Deep Sea Drilling Project*

Corvallis; Texas A&M University, College Station; University of Rhode Island, Kingston; Natural Environmental Research Council of the United Kingdom; and Centre National Pour l'Exploitation des Oceans (CNEXO) of France.

## *Geological Research Division*

The research group of Dr. Gustaf Arrhenius has studied problems associated with the removal of transition elements from seawater into the sediment, the secondary transport of these elements within the sediment, and their ultimate precipitation in the form of a number of discrete crystalline phases. These problems have a special bearing on the understanding of the formation of ferromanganese oxyhydroxide deposits, including manganese nodules, and the incorporation, in some of the phases in question, of comparatively large amounts of nickel, cobalt, and copper. In the course of these investigations, in cooperation with Dr. John P. Hunt, problems in the use of deep-sea deposits as mineral resources have been approached.

New research aspects include studies of the use of radiolarite deposits for high-strength, low-denisty monolithic construction materials with high thermal insulation, and the use of the unique surface properties of the oxide minerals in manganese nodules for catalysis. It was learned that after partial reduction and dehydration, the manganese oxide minerals in deep-sea nodules catalyze methanization of carbon monoxide at a rate comparable to that of commercial Fischer-Tropsch catalysts.

Dr. Saara K. Asunmaa proposed and demonstrated that radiation damage from natural radioactive elements in deep-sea sediments can produce activation sites for the oxidation of divalent manganese in seawater, and hence catalyze the oxidation reaction, which presumably leads to the formation of manganese oxide minerals on the sea floor.

*With Scripps Pier as backdrop, Director Nierenberg (center), talks with Sir Hugh Ennor (at right), Permanent Secretary of Australian Department of Commerce, Canberra, and E. G. Brown, Counselor (Scientific) of Australian Embassy in Washington, D.C.*

Graduate student Stephen E. Crane and Dr. Arrhenius have begun development of new techniques for synthesizing the manganese oxide minerals that form the major parts of the manganese nodules. Also they are attempting to determine the crystallographic sites of elements such as copper, nickel, and cobalt that substitute for other cations in the structure.

Graduate student R. Daniel Francis and Dr. Arrhenius studied the microscopic crystallization phenomena associated with transformation of olivine to serpentine and brucite, a reaction of major importance in the alteration of submarine basalts.

The Scripps Sediment Data Bank, directed by Jane Z. Frazer, assisted by Donna L. Hawkins and Mary B. Fisk, has added descriptions for about 9,000 marine sediment samples from the east Asia and southeast Asia areas in conjunction with the SEATAR (Studies of East Asia Tectonics and Resources) Program of IDOE (International Decade of Ocean Exploration)/CCOP (Committee for Coordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas)/IOC (Intergovernmental Oceanographic Commission).

About 200 manganese nodules selected from the Equatorial Pacific were assayed by X-ray fluorescence energy spectroscopy. Sources of systematic error in this application of the technique were studied. Experiments were undertaken to find solutions to these problems and determine valid procedures for manganese nodule analysis.

The new nodule assays, plus other analyses obtained from the literature and additional information obtained by analysis of sea-floor photographs, were also added to the sediment data bank. These data have been provided to several government agencies and interested scientists, and are also being used as a basis for studying the origin and development of deep-sea ore deposits.

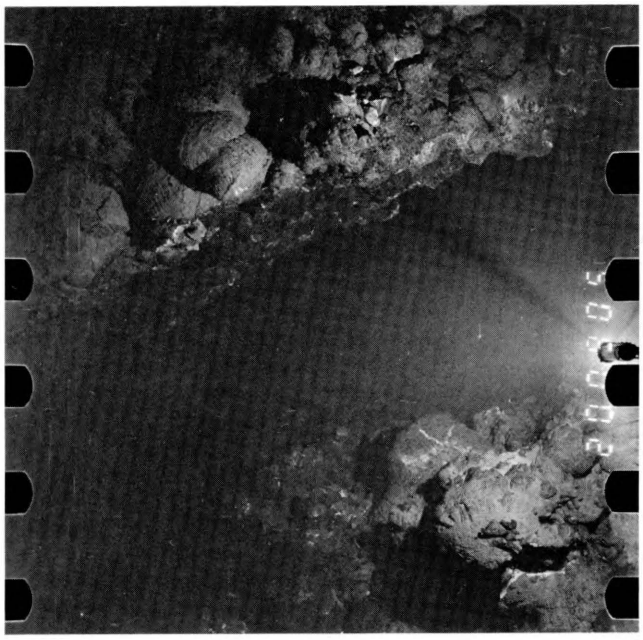
Drs. Wolfgang H. Berger, Edith S. Vincent, and John S. Killingley are studying deep-sea sedimentation and ocean history. Their work focused on three major projects: (1) processes at the sea floor in carbonate-rich areas, using box-cores; (2) the environmental significance of foraminiferal remains in deep-sea sediments, as reflected in their oxygen and carbon isotopic composition; and (3) the nature of acoustic reflectors in calcareous sediments, notably their dependence on depth of deposition.

Thirty box cores were recovered that for the first time allowed the exact determination of rates of sedimentation and of dissolution of carbonate on the sea floor. These rates play a large role in the $CO_2$ budget of earth, a budget that is being strongly disturbed by the input of industrial $CO_2$ into the atmosphere.

The stable isotope studies have yielded important information on the variability of composition within and between foram species. Isotopic composition has been used somewhat indiscriminately to infer conditions about past oceans. It now seems that the reconstruction of ocean history is much more complicated than had been assumed.

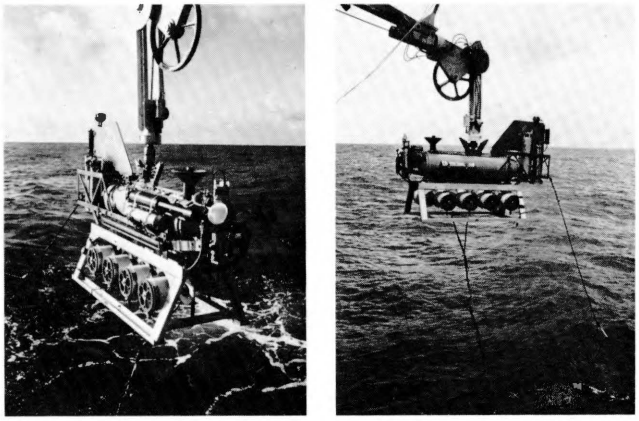
The nature of seismic reflectors within carbonate sequences is closely associated with the conditions of deposition. These initial conditions determine how the sediment changes after being buried, that is, its diagenesis. In turn, diagenetic processes determine sound velocity. The effect of changing conditions of carbonate dissolution through the last several million years is being explored by Dr. Berger, together with Dr. Edward L. Winterer and graduate student Larry A. Mayer.

Dr. Joseph R. Curray completed his three-year term as Chairman of the SIO Graduate Department in December 1975, and took six-months sabbatical leave at Imperial College, London, January through June 1976. During this



*View of fissure on spreading axis in center of axial graben of Galápagos Spreading Center (~1°N, 86°W), from which plumes were sampled that contained high $He^3/He^4$ ratios and radon concentrations. Strobe light attached to Deep-Tow vehicle that took photograph was positioned at 1.5 m above sea floor; fissure is about 2.5 m wide. Operation took place during Pleiades Expedition.*

*Marine Physical Laboratory*



*Taken from deck of R/V* Melville, *these two photographs show "sampling sled" with array of eight hydrographic bottles and CTD sensor attached beneath Marine Physical Laboratory-developed Deep-Tow vehicle during its utilization on Pleiades Expedition. A hydrothermal plume highly enriched in $He^3$, $He^4$, and $Rn^{222}$ was successfully sampled on Galápagos Spreading Center.*

*Drs. Harmon Craig, Raymond F. Weiss, John E. Lupton, and Yu-chia Chung*

period he continued analysis and publication of the work he and his colleagues have been doing for the past several years in the northeastern Indian Ocean. This work, with Dr. David G. Moore and Frans J. Emmel, included a description of a large submarine slide (olistostrome) at the base of the continental slope off Burma and overlying the Bengal Deep-Sea Fan. The total area covered by this slide is almost 4,000 $km^2$, and its total volume is over 900 $km^3$. Other research with Dr. Venkatarathnam Kolla of Lamont-Doherty Geological Observatory, Dr. Moore, and James C. Yount, graduate student, demonstrated the existence and importance of contour currents flowing southwestward, parallel to the bathymetric contours on the west side of the Bay of Bengal. Studies were also carried out on the tectonics of the Andaman Sea, the morphology and sedimentary processes of the Bengal Deep-Sea Fan, and the structure of the Banda and eastern Sunda arcs, Indonesia.

Dr. Robert L. Fisher, in collaboration with Dr. Celeste G. Engel and others, continued laboratory study of the distribution and composition of igneous rocks of the lower crust recovered from the mid-ocean ridge system of the western Indian Ocean and the trench-island-arc marginal zones of the western Pacific.

In shipborne field work, Dr. Fisher acted as a senior scientist on a one-month dredging, gravity, seismic-reflection, magnetic, and topographic investigation of the Southwest Indian Ridge and the triple junction in the western Indian Ocean. The program, on a traverse between Durban, Republic of South Africa, and Mauritius, was carried out aboard Woods Hole Oceanographic Institution's (WHOI's) *Atlantis II* with participation by Woods Hole, Massachusetts Institute of Technology (MIT), Scripps, and South African scientists. Varied suites of fresh to somewhat altered mafic and ultramafic plutonics of the deep crust, as well as tholeiitic extrusives, were recovered from several levels in major north-south, very deep, cross-fractures discovered or delineated on this cruise. Fresh to variously altered tholeiites were recovered from the topographically and magnetically anomalous northeast sector of the southwest branch, and the triple junction was precisely located for subsequent detailed magnetic-topographic study by WHOI-MIT scientists.

The record of pollution history in coastal marine, glacial, and terrestrial sediments has been the focus of investigations carried out by Dr. Edward D. Goldberg and his associates, Minoru Koide, Dr. Vernon F. Hodge, and Kathe K. Bertine. Scripps scientists, in collaboration with scientists from the Johns Hopkins University, Baltimore, studied sediments from Chesapeake Bay, Maryland. Not only was increasing heavy-metal pollution revealed in recently deposited strata, but the 1972 major Hurricane Agnes was evidenced by a layer of 20 to 70 cm of relatively homogenous solid phases near the sediment/water interface. Most of the metal pollutants such as copper and zinc had sources in industrial wastes, while the lead contamination was associated with the combustion of lead alkyls in gasolines. Similar studies had been carried out on sediments in Narragansett Bay, Rhode Island, and from the Pacific Ocean, off the California coast.

The record of atmospheric pollution in Tokyo was noted in sediments. These sediments, taken from the moat surrounding the Emperor's Palace, which is located in the center of the city, showed that metal pollution appeared to follow the economic history of Japan over the past 30 years. In the ten-year depressed period following World War II, such metals as silver, chromium, and zinc had decreasing fluxes to the sediments and presumably lower concentrations in the air from which they entered the deposits. From the period 1955 to the present there are increased levels in the sediments.

The distances seaward from the coast of California at which man-mobilized, heavy-metal pollutants, such as lead, vanadium, and zinc, can be detected in the sediments were also investigated. The increased concentrations caused by man could be found at least 100 km from land. The values fall off as the square of the distance from shore. Atmospheric transport, as opposed to river or sewer outfall

inputs, appears to be in accord with Dr. Goldberg's measurements.

The atmosphere as a transport path for both pollutant and natural heavy metals has been investigated through analyses of dust collected in La Jolla, California, and in Baja California, Mexico. A substantial fraction of heavy metals, including plutonium, lead, nickel, silver, and copper, is carried to the marine environment by atmospheric dusts in an easily leachable form. Such a leaching in the oceans can measurably influence the composition of surface waters. One of the unexpected results off southern California is the remarkable constancy in dust fluxes to the oceans throughout the year and the corresponding uniformity in their composition with respect to heavy metals.

The transuranic elements plutonium and americium have been introduced into the environment in measurable amounts, primarily as a consequence of weapons testing. A substantial portion of such materials entered the stratosphere, from where they continue to fall to the earth's surface. In collaboration with workers at the State University of New York, Buffalo, the scientists have recorded such measurements in the Greenland Glacier and in estuarine and coastal sediments off the United States and South America. The glacial record involves atmospheric fallout; the coastal marine sediments record both the atmospheric fallout and the entry of terrestrial fallout on wind- or river-borne soil particles. Such studies will aid in the management of transuranic pollution from nuclear reactors and from nuclear reprocessing plants.

The introduction of a time frame is of paramount importance to appropriately develop pollution histories in sediments. Several radiometric techniques have been developed for application in coastal sediments over the past years. A new technique was discovered that involved the isotope radium-226 with a half-life of 2,600 years. The nuclide, in the virtual absence of its parent thorium-230, enters the sediments incorporated in phytoplankton. The sensitivity of this method depends upon the ratio of amounts of parent and daughter in the deposits. The method was applied to a sediment taken off the coast of California in the San Clemente Basin, a deposit that could not be dated over a period from the present to 3,000 years ago by other radiometric means.

A national monitoring program for marine pollution has been initiated, in collaboration with researchers from Woods Hole Oceanographic Institution, Massachusetts, the University of Texas at Austin, UC Berkeley, and the Moss Landing Marine Laboratories, California. Mussels, chosen as sentinel organisms to record pollution in coastal areas, were being collected from the western, eastern, and gulf coasts of the United States by Eric D. Gamble and Lynn C. Gamble traveling in a camper equipped with laboratory facilities. Four sets of pollutants were being analyzed: heavy metals; halogenated hydrocarbons, including pesticides such as DDT and dieldrin and the industrially used polychlorinated biphenyls; artificial radioactivities; and petroleum. Laboratories on the east coast and west coast were analyzing each group of pollutants. During the first year of operation, 125 stations were being sampled.

Dr. James W. Hawkins' group has continued its studies of igneous rocks of the oceanic crust and in the volcanic areas of oceanic margins. Some of the Pacific Ocean areas studied include the North Fiji Plateau and the Lau Basin, where young oceanic crust has been formed in areas behind island arcs, and the Samoan volcanic chain, which is a young linear volcanic chain built on old oceanic crust. Graduate student Rodey Batiza has continued his studies of seamounts and volcanic islands, which will be the main topic of his dissertation. Batiza has completed field studies on Isla Tortuga and Guadalupe Island off the coast of Baja California, Mexico. Dr. Richard K. Nishimori completed his doctoral dissertation on the layered gabbros of the Cuyamaca Range in San Diego County. The layered gabbros represent the roots of andesitic volcanoes of a Mesozoic volcanic arc.

A new project, concerned with the origin of porphyry copper deposits in island arcs, is part of the International Decade of Ocean Exploration/National Science Foundation studies of tectonic processes and resources of the southwestern Pacific Basin. Field and laboratory work has been conducted on the islands of Luzon, Yap, Palau, and Guam and in the Yap-Palau island-arc area.

The Isotope Laboratory research group carried out extensive studies of mantle-crust interaction and geothermal phenomena in continental rift zones and oceanic spreading areas. Drs. John E. Lupton and Harmon Craig identified a new "primordial" component, excess neon-20, in Kilauea Crater volcanic gases and tholeiitic basalts from the East Pacific Rise; the excess $Ne^{20}$ is correlated with the amount of excess $He^3$, a primordial mantle component that Drs. Lupton and Craig previously identified in ridge-crest tholeiites. Mantle hydrogen, identified by a unique deuterium-to-hydrogen isotopic ratio, was also observed in basalt glasses from the East Pacific and Mid-Atlantic rises.

In early 1976 Drs. Craig and Lupton, together with Valerie Craig and Ross M. Horowitz, spent six weeks in the Ethiopian Rift Valley conducting geochemical studies in geothermal regions in collaboration with United Nations Development Program and the Ethiopian government. At that time helium concentrations in geothermal water and gases from the southern border to the Afar Depression were mapped with a portable helium mass spectrometer, in continuation of studies carried out previously in the Lake Tanganyika and Kenya Rift zones.

With Dr. Yu-chia Chung this group also continued their earthquake prediction studies in southern California, monitoring helium isotopes, radon, and other parameters in thermal wells and springs along the major faults. These studies have shown that primordial $He^3$ from the mantle is found in the Imperial Valley, California, along the San Andreas fault. Such is not the case in the African Rift samples, at least in data analyzed to date.

An extension of the above studies to hydrothermal phenomena in basalts along spreading centers was carried out by the Isotope Laboratory group on Pleiades Expedition in the spring of 1976. Their measurements on the Red Sea geothermal brines had shown that these brines contain large quantities of the primordial $He^3$ component, so much that it was clear that $He^3$ and total helium should be the most sensitive indicators for hydrothermal circulation of seawater in basalts on active spreading centers — a process deduced from heat-flow patterns, but never observed directly. Thus, a program for detection of deep-sea hydrothermal plumes was initiated. This program was carried out in collaboration with the Deep-Tow research group and the GEOSECS (Geochemical Ocean Sections Study) Operations Group.

Dr. Raymond F. Weiss and Arnold E. Bainbridge designed a "sampling sled" with an array of hydrographic sampling bottles and a continuously recording CTD for mounting on the Deep-Tow vehicle (see illustrations). Drs. Weiss and Peter F. Lonsdale, while serving as cochief scientists on Pleiades Expedition, deployed the sampling sled and Deep Tow in surveys of suspected "plume" sites on the East Pacific Rise and Galápagos Spreading Center.

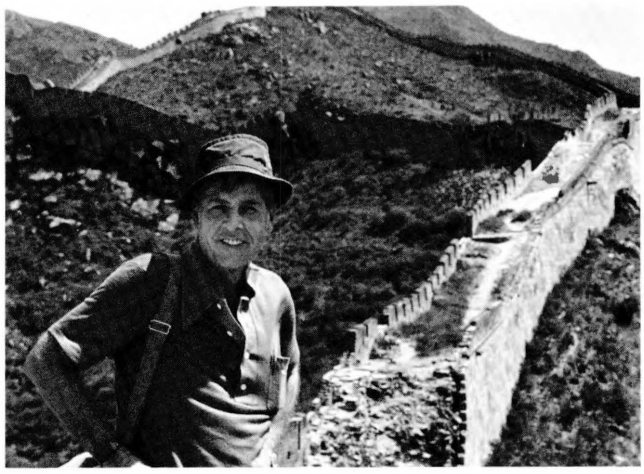
Spikes of anomalously warm water were observed to emanate from a 3-m fissure along the central axis of the Galápagos Spreading Center. (Similar spikes of warm water were encountered at other sites and on the East Pacific Rise, but potential temperature and salinity properties of most of these spikes showed they were produced by mixing of dif-

ferent water masses rather than by hydrothermal emanations. The use of a continually recording CTD is essential for distinguishing mixing spikes from hydrothermal plumes.) Shipboard radon analysis by Dr. Weiss and $He^3$ measurements by Dr. Lupton showed that the true spikes on the central fissure in the Galápagos area corresponded to the 100 percent enrichment in the $He^3/He^4$ ratio and a three-fold radon enrichment relative to "background" water, thus giving the first positive identification of a deep-ocean hydrothermal plume.

Dr. Lupton completed measurements of $He^3/He^4$ ratios in dissolved helium at four GEOSECS stations that form an east-west section across the Mid-Atlantic Ridge at 30°N. The helium isotope ratios observed in the deep water at these stations are within a few percent of the atmospheric ratio, indicating that the Mid-Atlantic Ridge is not a significant source of injected $He^3$ at this latitude. These results are in sharp contrast to $He^3/He^4$ ratios in the deep water on the East Pacific Rise, which are 20 to 30 percent higher than atmospheric because of injection of primordial helium during generation of new oceanic crust. During South-Tow Expedition, Dr. Lupton measured $He^3/He^4$ ratio in an east-west section across the East Pacific Rise at 14°S. These samples are of particular importance because they were collected directly over one of the most active spreading areas. They show a broad mid-depth $He^3$ maximum east of the rise with $He^3/He^4$ about 30 percent above atmospheric increasing to about 35 percent on the crest of the rise, thus confirming the previously reported large $He^3$ anomaly in the eastern equatorial Pacific.

Dr. Chung continued his studies of global oceanic Ra-226 variations by measuring GEOSECS Pacific samples. He completed the eastern half of an E-W section in the North Pacific. For the first time, results indicate that there are cores of maximum Ra concentration in the northeast Pacific deep water probably produced by local sources and horizontal mixing. He also studied the Pacific Ocean benthic front, and mapped the "scale height" of the deep and bottom waters in the Pacific. Together with Dr. Craig and graduate student Michael D. Applequist, Dr. Chung studied the Pb-210/Ra-226 disequilibrium system in the oceans and offshore basins. They found that the particulate Pb-210 concentration increases systematically with depth in the Pacific deep water, thus supporting the particle-scavenging hypothesis.

Drs. Craig and Weiss continued work on the global distribution and time variation of atmospheric nitrous oxide. This trace gas plays the principal role in modulation of the earth's ozone layer, which, in turn, limits the penetration of solar ultraviolet radiation to the earth's surface. Recent suggestions that man's activities may be producing significant quantities of atmospheric nitrous oxide have emphasized the importance of this research. Samples collected by the late graduate student William L. Dowd on Carrousel Expedition during 1964 were analyzed at the same time as samples of 1974 marine air collected during a GEOSECS expedition. These measurements showed that atmospheric nitrous oxide increased by approximately 1.5 percent over the decade, an effect that is attributed to anthropogenic sources. Dr. Weiss measured nitrous oxide production by the industrial combustion of coal and fuel oil, and found that up to half of the observed increase can be caused by combustion of fossil fuels. A projection of the observed increase to the year 2000 predicts a 9 percent increase in atmospheric nitrous oxide and a corresponding 2 percent decrease in the ozone layer. The ozone decrease will become serious during the early part of the twenty-first century; the present rate of $N_2O$ increase corresponds to a 25 percent $O_3$ decrease by the year 2050, according to present knowledge of the $N_2O$-$O_3$ modulation effect.

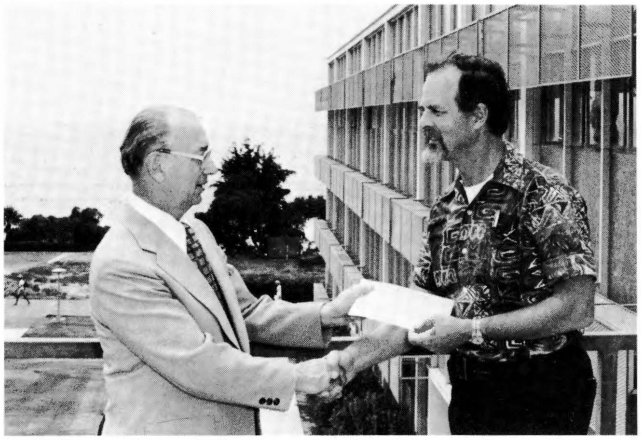


*Dr. Harmon Craig, who spent three weeks during June 1976 studying Chinese methods for earthquake prediction in the People's Republic of China, took time out to do some sightseeing, and is shown here atop the Great Wall of China.*
*Dr. Amos M. Nor*
*Stanford University*

Valerie Craig continued to study the provenance of classical Greek marbles using the isotopic techniques developed for this work. A study of samples recently collected in the Acropolis and the Athenian Agora and from the quarries and temples of Sounion, showed that portions of the temple of Athena at Sounion had been transported to Athens by the Romans and reused for building stones, thus confirming the "traveling-temples" hypothesis of Dr. Homer A. Thompson of Princeton University, New Jersey. They also studied the ceiling coffers of the "Thesion," the oldest building in the Athenian Agora, and showed that these were not made of the famous Parian "Lychnites" marble as had been supposed, but are instead Pendelik marble from the nearby quarries on Mt. Pendelikón.

During June 1976, Dr. Craig was one of ten scientists from the United States who visited the People's Republic of China (PRC) to study the methods used by the Chinese in predicting the 1975 Haicheng earthquake in the Province of Liaoning. The group spent three weeks in Manchuria, Peking, and Shanghai, investigating all aspects of Chinese earthquake prediction methods, including animal behavior. Dr. Craig was permitted to collect geothermal water samples, for helium and helium isotope measurements, and to bring them back to the campus for his own reserach, the first time this has been allowed. It was evident that the Chinese have obtained considerable data from, and have assigned many persons to work on, the prediction studies. The visit by the scientists from the United States was jointly sponsored by the Committee on Scholarly Communications with the PRC (the U.S. group) and the National Scientific and Technical Association of PRC (the Chinese group).

Dr. Thomas H. Jordan's research has focused on the refinement of kinematical models of present-day plate motions and on the problem of mapping lateral heterogeneities in the earth's mantle. Working with graduate student Stuart A. Sipkin, Dr. Jordan has used the observed variations in seismic-wave velocities to argue that continents have thick "roots" extending to depths as great as 400 km. Analysis of seismic records from a deep-focus earthquake in the Kuril Arc in the Northwest Pacific has demonstrated the existence of a zone of high seismic velocities extending below the Benioff (earthquake) Zone, thus suggesting that



*Associate Director George G. Shor, Jr. (at right), accepts check from Texaco, Inc., to be used for research and scholarships. W. C. Lenz, manager of Texaco's Los Angeles Division Producing Department-West Coast U.S., makes presentation marking firm's continuing support of Scripps's Industrial Associates program.*

the lithospheric slab penetrates the lower mantle beneath this subduction zone.

The first phase of Dr. Miriam Kastner's experimental study of the chemical controls on the rate of transformation of siliceous oozes to porcelanite has been completed. Dr. Kastner and graduate student John B. Keene are concentrating on the transformation of porcelanite to chert.

The results of the first phase show that evidence from deep-sea sediments supports this diagenetic maturation sequence: opal-A (siliceous oozes) → opal-CT (porcelanite) → chalcedony or cryptocrystalline quartz (chert). A solution-redeposition mechanism is involved in the opal-A to opal-CT transformation. Exceptions to the overall maturation sequence are numerous, suggesting that temperature and time are not the only important factors that control these mineralogical transformations. The rates of the above transformations are strongly affected by the composition of the solution and of the host sediments; in Mesozoic clayey sediments opal-CT predominates, while in carbonate sediments quartz predominates.

Experiments at 25 °C and 150 °C over a period of one day to six months show that the transformation rate of opal-A to opal-CT is much greater in carbonate versus clay-rich sediments. In the role of carbonate, opal-CT nucleation is aided by the precipitation of magnesium hydroxo complex nuclei. In carbonate sediments the dissolution of carbonate provides the necessary alkalinity, and seawater provides the magnesium for the magnesium hydroxo complex nuclei. In contrast, in clay-rich sediments the clay minerals compete with opal-CT formation for the available alkalinity, for ($OH^-$), mainly from seawater. As a result, the clays transform to a Mg-rich clay, and the rate of opal-CT formation is highly reduced. This mechanism also bears on the common observation of carbonate replacement by silica in cherts.

Keene is completing his PhD thesis on "The Origin of Cherts in the Pacific and their Paleoceanographic Implications." He concluded that an analysis of the distribution of biogenic and authigenic silica in the Pacific Basin has shown that chert occurrences can be explained by diagenesis of biogenic silica as influenced by paleogeographic and oceanographic factors. The middle Eocene chert is the result of diagenesis and does not represent a change in the silica budget or volcanism at that time. Sediment composition, time, and temperature influence the distribution patterns of cherts; chert is found in younger sediment when carbonate is present and when the biogenic silica is present as diatoms, and in areas of high heat flow.

Dr. Kastner and graduate student Sharon A. Stonecipher studied zeolites in pelagic sediments of the Atlantic, Pacific, and Indian oceans. The four major results of this study follow:

(1) Quantitatively, zeolites are among the most important authigenic minerals in pelagic sediments. Phillipsite and clinoptilolite are the two most common zeolites in deep-sea sediments. Other zeolites that occur in deep-sea sediments are analcime, chabazite, erionite, gmelinite, harmotome, laumontite, thomsonite, thaumasite, and natrolite. Analcime is the most abundant zeolite.

(2) Phillipsite is associated with argillaceous, volcanic, and siliceous sediments; it occurs in areas and sediments of slow sedimentation rates, at shallow depths in the sediment, and in very young sediments. It also occurs in sediments that show visible or chemical evidence of volcanic glass or palagonite. Phillipsite is most frequently associated with smectite, at least part of which is probably authigenic. Its apparent dissolution at depth may indicate that it is thermodynamically unstable in the marine environment.

(3) Clinoptilolite, which is associated with calcareous and opal-CT-rich (with or without opal-A) sediments, occurs in areas and sediments of high sedimentation rates and in sediments of lower Pliocene and older. The youngest clinoptilolite-bearing carbonate sediments are significantly younger than the youngest clinoptilolite-bearing clayey sediments. Even in the presence of carbonate, clinoptilolite forms in older sediments than phillipsite. Clinoptilolite is associated with primarily detrital smectites and illites in younger sediments and in older sediments with palygorskite and illites, which are probably authigenic.

(4) The most common precursor for the phillipsite seems to be palagonite. Clinoptilolite seems to be able to form from both volcanic and nonvolcanic precursors. Possible precursors for clinoptilolite include rhyolitic to andesitic glass; basaltic glass + silica (mainly biogenic); smectite + phillipsite + biogenic silica; and perhaps smectite + biogenic silica. Analcime and the other more Ca-rich zeolites are associated with basaltic volcanic material.

Dr. J. Douglas Macdougall and students continued to work in several areas of nuclear geology and geochemistry. Studies with graduate student Mark E. Andersen of a new and simplified method for measuring accumulation rates of manganese nodules and deep-sea sediments have been successful. The technique involves alpha-particle radiography and permits very high-resolution, nondestructive measurements of radioactive species *in situ.* Accumulation rates of most manganese nodules investigated fall in the range of 2-10mm/$10^6$ yrs., in agreement with results of much more laborious conventional methods. Several interesting "anomalous" total alpha profiles have been measured; these may be the result of differential growth rates in various portions of single nodules and growth discontinuities. In collaboration with scientists at Lamont-Doherty Geological Observatory of Columbia University, and The Physical Research Laboratory, Ahmedabad, India, Dr. Macdougall is making precise characterizations of the uranium-series decay daughters by radiochemical methods, in order to aid in interpretation of the alpha activity profiles.

Investigations of the behavior of uranium during sea-floor, rock-weathering processes continue. Preliminary uranium isotope measurements indicate that seawater is the source for uranium enrichments observed in weathered basalts, and that it may provide a semiquantitative time scale for the process. Chemical analysis of altered basalts in which uranium con-

centrations are high have provided useful normalizations for mass-balance calculations.

Dr. Macdougall has continued investigations into the origin and evolution of carbonaceous chondrites, a group of meteorites that may be keystones to the interpretation of the chemical evolution of the solar system and that may have provided many of the volatile components which make up the earth's atmosphere and oceans. A new method for determining the compaction ages of these loosely consolidated meteorites has been developed. Dr. John F. Kerridge, UC Los Angeles, and Dr. Macdougall probed the nature and significance of the anhydrous phases in the most primitive of the carbonaceous chondrites. Working with colleagues at UC Berkeley and the University of Chicago, Dr. Macdougall studied the early irradiation and microparticle bombardment of carbonaceous meteorites.

New research projects include fission-track dating studies of rocks from the southern California batholith, in collaboration with student Richard W. Carlson; dating of local archeological sites by the fission-track method by using "baked" cobbles; and a collaborative project with Drs. Gunter W. Lugmair and Kurt Marti, of the UC San Diego Chemistry Department, on the use of isotopic ratios of the rare-earth element neodymium as a tracer for magma generation and crustal evolution processes, particularly for oceanic and oceanic island rocks.

Two other new projects of Dr. Macdougall, in collaboration with Drs. Yu-Chia Chung and Harmon Craig, involved developing a method of measuring integrated radon fluxes from the ground as a possible earthquake-related phenomenon by using alpha-sensitive film; and measuring uranium isotopic ratios in southern California thermal waters.

In a project with Dutch biostratigraphers, Dr. William R. Riedel and Annika Sanfilippo have detected variations in Pliocene radiolarian assemblages from Sicily, which are tentatively interpreted as paralleling changes in the general biological productivity of that area. M. Jean Westberg is attempting to determine whether similar variations in Pacific radiolarian assemblages reflect present-day patterns of gross biological productivity. Sanfilippo continues a long-term study of European Mesozoic radiolarians.

Patricia S. Doyle and co-workers are refining the Tertiary and late Mesozoic stratigraphy of microscopic fish skeletal debris (ichthyoliths), and are using them to determine the ages of some parts of Deep Sea Drilling Project cores that lack the more familiar planktonic microfossil groups.

Dr. Francis P. Shepard and his associates made considerable progress on canyon current studies. They had found previously that the time period of cycles of alternating upcanyon and downcanyon currents increased with water depth until the time period agreed with that of the semidiurnal tide. They had also learned that with 1- to 2-m tides, the depth of reaching this tidal period was of the order of 250 m, and that it was of the order of 1,600 m with tides of less than a meter. Present studies show that with a tide of 4 m, the depth is at least as shallow as 85 m. It was also established that currents frequently flow across the canyon axes during the time of slack tides.

It was learned that turbidity currents of relatively low velocity are related to large swell. New instruments are being constructed to measure turbidity currents of high velocity that carry away current meters.

Neil Marshall discovered a new tributary on the south wall of Scripps Canyon. The tributary resulted from recent slumping that appears to have accompanied a period of large waves.

Gerry Kuhn, in his studies of California coastal erosion in the Del Mar-to-Encinitas area, has made the important discovery that the rate of cliff erosion is much faster in that area than engineers had considered it. His investigations have proved of interest to the California Coastal Zone Conservation Commission. Kuhn has linked periods of unusually large waves and unusual floods to the fast retreat of the cliffs. Entire city blocks of Encinitas and Oceanside, California, have disappeared since the late nineteenth century.

Dr. Hans R. Thierstein has completed a stratigraphic study that showed the youngest two biostratigraphic coccolith events, the extinction of *P. lacunosa* and the first appearance of *E. huxleyi,* are synchronous from 54°N to 46°S and occurred during oxygen isotope stage 12 and stage 8, respectively. An investigation was initiated into the paleobiogeography, preservation, and paleoecology of calcareous nannofossils at the end of the Mesozoic and their paleoceanographic and paleoclimatic implications.

## *Marine Biology Research Division*

Investigations in the Marine Biology Research Division embrace experimental, descriptive, and biological disciplines including physiology, biochemistry, microbiology, developmental and systematic biology, and ecology of the sea. Many of the studies are comparative in nature, 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 a better understanding of marine organisms and the manner in which they adapt to life in the sea.

Lipids are the primary medium for energy transfer in marine food chains. These fats and oils are compact and buoyant energy resources for marine animals as they are for man and his machines. In the deep sea and in many life forms of the tropical and temperate oceans, the major energy reserve is a lipid of special structure and physical properties, wax ester. Dr. Andrew A. Benson studied the role of wax in oceanic food chains.

Studies by Dr. John S. Patton have revealed the central role of a new enzyme system. With it, fish have adapted to their need to utilize the energy in wax esters stored by organisms. Dr. Benson and his colleagues believe that they have discovered a major biochemical mechanism by which corals have been able to survive in tropical waters almost devoid of adequate nutrients. Their symbiotic algae convert the animal's end product, acetate, back to long-chain fatty acids of considerable energy content. This cyclic process appears to be an important factor in the coral's ecological success in the tropical oceans.

The current U.S. Bureau of Land Management-sponsored base line study of petroleum hydrocarbon accumulation in waters, sediments, and marine organisms of the Southern California Bight area has involved a portion of the activity of Dr. Benson's laboratory. Samples of benthic and intertidal animals have been processed and analyzed for high molecular-weight hydrocarbon content revealing a broad range of natural and man-produced contaminations.

In the laboratory of Dr. Theodore Enns, the mechanisms of carbon dioxide transport in animals and plants are being analyzed. Collaborating with Dr. Esther Hill, UC San Diego School of Medicine, he has studied carbon dioxide diffusion in dog lungs and measured carbonic anhydrase of tissue extracts. Analysis of the data shows that facilitation of carbon dioxide diffusion across the alveolus-capillary barrier is caused by carbonic anhydrase activity and exists only when there is enzyme activity.

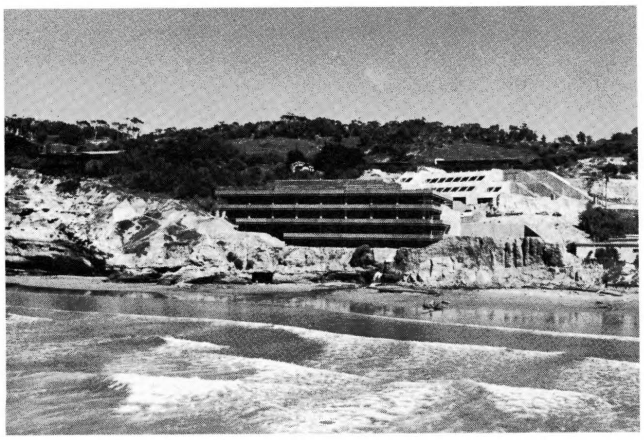
Dr. Dale A. Kiefer, in collaboration with Dr. Enns, has completed a steady-state model of light-, temperature-, and carbon-limited phytoplankton growth. This thermodynamic

model was the initial step in an analysis of phytoplankton growth, and predicts chlorophyll and enzyme levels under various limiting conditions.

Research from Dr. David Epel's laboratory continues to center on early embryonic development of marine invertebrate organisms. Work done with Dr. James D. Johnson, and with Dr. Miles Paul, University of Victoria, British Columbia, has resulted in an important breakthrough in the understanding of how egg metabolism is turned on after fertilization. They have learned that about one minute after fertilization, an ion exchange mechanism is activated that exchanges extracellular sodium for intracellular hydrogen. The result is an increase in the cytoplasmic pH. This change appears to be critical for initiating development. A second important insight has come from the research of Franklin D. Collins, UC San Diego graduate student, on changes that take place in the sperm preparatory to fertilization. His work has indicated that the "egg jelly," a gelatinous matrix present around many marine eggs, alters the behavior of sperm similar to chemotaxis. Sperm come together and adhere to each other in tiny rosettes. This behavior may be important in insuring that the sperm make successful contact with the egg as a part of the fertilization process.

Dr. Denis L. Fox continued his studies on the nature of animal biochromes and the metabolic fate of ingested carotenoids. Dr. Fox had papers on many aspects of this topic published during the year.

Dr. Francis T. Haxo and associates continued their studies of photosynthesis and carotenoid composition and function in dinoflagellates and other microalgae. Detailed characterizations of the peridinin-chlorophyll *a* complexes, important light-harvesting components in dinoflagellate photosynthesis, were published this year, based upon separate studies by Dr. Barbara L. Prézelin and collaborative efforts of Dr. Haxo and Dr. Harold W. Siegelman, Brookhaven National Laboratories, New York. An inference from these studies is that the multiplicity observed in the protein components of the complexes may be species specific and thus useful for taxonomic purposes.



*Photograph taken in the spring of 1976 shows construction progress on $5 million Marine Biology Research and Instruction Building (foreground) and $2.5 million Scripps Library just behind it. January 1977 is the target date for occupancy of the library and completion of the marine biology building. The three-story, 3,000 m² library will accommodate more than 150,000 volumes; the four-level, 6,500 m² marine biology building will be used primarily for classrooms and laboratories.*

*Jackie Janke*

Collaborative studies by Dr. Pill-Soon Song and S. Koka of Texas Tech University, Lubbock, and Drs. Prézelin and Haxo on the photochemical properties of the aforementioned chromoprotein complexes led to proposal of a possible model for the molecular arrangement of peridinin and chlorophyll *a* in the chromoprotein complex.

Reexamination of the photosynthetic action and absorption spectra of coccolithophorids is in progress. Preliminary results indicate that the novel carotenoid 19′-hexanoyl fucoxanthin, like fucoxanthin, functions as an auxiliary light-harvesting pigment in coccolithophorid photosynthesis.

Nancy W. Withers, a graduate student, in studies of the biochemistry of isolated oil globules from the binucleate dinoflagellate *Peridinium foleaceum,* has recently detected the presence of phytol esters of long-chain polyunsaturated acids and has contributed to the understanding of pathways that led to the accumulation of β-carotene and γ-carotene.

Deep-sea research continued along varied courses in Dr. Robert R. Hessler's laboratory. Major effort has been directed toward the systematics, distribution, and evolution of one of the most important deep-sea groups, the isopod crustaceans. Samples from a series of transects ringing the Atlantic Ocean reveal as many as 90 isopod species living together at one spot. Significant strides have been made toward the long-term goal of straightening out the confused general taxonomy of the group. A paper was published arguing that the extensive deep-sea isopod fauna is a result of *in situ* evolution rather than invasion from the shallow-water antarctic, as has been most frequently argued.

As part of the deep-sea community studies in the Pacific, an analysis of spatial distribution of benthic foraminifera has been completed. In contrast to most of the previous findings from the deep sea, their distribution proves to be quite patchy. The use of multivariate techniques has demonstrated that some of this patchiness can be related to the distribution of manganese nodules and to other members of the fauna.

Dr. Nicholas D. Holland has continued to investigate the reproductive biology and embryology of feather stars. Part of this work is being carried out at the Misaki Marine Biological Laboratory in Japan. From monthly samples of the Japanese feather star, oogenesis and spermatogenesis have been described in detail. Also, the fine structure of the developing embryos has been described; the cytoembryological mechanisms of gastrulation are of special interest. The comparative spermatology of crinoids is another topic currently under study. It now appears that brooding crinoids of the antarctic seas have a highly specialized sperm type.

Dr. Carl L. Hubbs actively continued his researches during the year. Highlights included the completion of studies in collaboration with Dr. Bo Fernholm, a visiting scientist from Sweden, on two phases of the research on the hagfishes of the world, dealing specifically with the preparation of systematic revisions of the eastern Asiatic and the western Atlantic species. Collaborative systematic studies with Dr. Robert Rush Miller, University of Michigan, Ann Arbor, on the freshwater fishes of eastern Mexico were continued. Several joint reports were written on the biology of the marine mammals of the eastern Pacific, along with one on the ridley sea turtle. Researches on the marine fishes, particularly of California, were continued throughout the year. With Dr. Tomio Iwamoto, California Academy of Sciences, San Francisco, a study of the three new bathypelagic macrourid fish was completed during the winter, for publication in the *Proceedings of the California Academy of Sciences.* Collaboration with the San Diego Society of Natural History, the Zoological Society of San Diego, Sea World, Inc., of San Diego, and several organizations, was continued throughout the year, with particular emphasis on expanding the scientific work of these institutions.

Dr. Elizabeth Kampa, continuing her work with photoregulated vertical migrations of mesopelagic animals and the dependence of these migrations on fluctuations in photoenvironment, has devoted the year to two phases of the study: (1) the compilation of 20 years' data on photoenvironment in the upper 1,000 m of ocean in the eastern subequatorial and equatorial Pacific; (2) the acquisition of what Dr. Kampa considers the most reliable means of collecting these animals from their mid-water habitat, the RMT (rectangular mid-water trawl) designed by the Institute of Oceanographic Sciences, United Kingdom. The trawl as used initially by Dr. Kampa had a mechanical opening and closing device. Recently, Dr. Kampa has been able to obtain the IOS-designed acoustic environmental monitoring and opening-closing release gear for this trawl.

During shake-down cruises, fishing horizons for the 4-$m^2$ trawl are controlled to within 1 to 2 m of depth. Precise times of opening and closing (on command from deck) are clearly indicated in the acoustic record. Environmental parameters are recorded on deck at 2-second intervals. The entire assembly has been used at sea off San Diego, and will be employed to examine horizons from 1,000 m to the surface off the Marquesas Islands in the summer of 1976.

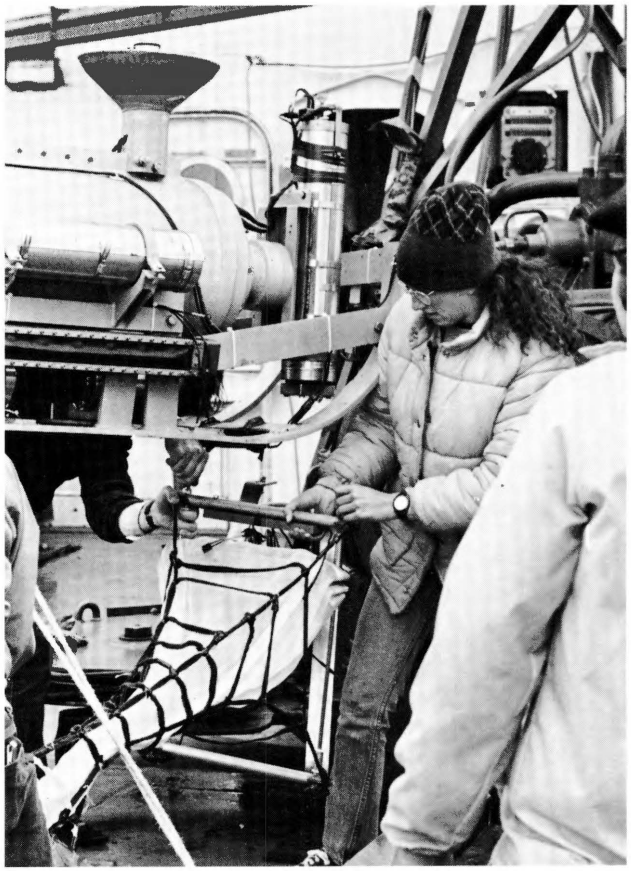
Dr. Kenneth H. Nealson has been studying various aspects of the symbiotic relationship between luminous bacteria and marine luminous fishes. Dr. Nealson has shown that the luminous bacteria possess a unique mechanism called autoinduction by which they control the synthesis of the luminous system. Edward G. Ruby, a graduate student, has shown that the bacteria excrete organic acids, and on the basis of his findings, has proposed a model of the physiology of the symbiotic relationship. Collaborative work with Dr. J. Woodland Hastings, Harvard University, Massachusetts, has revealed that these symbioses are species specific; that is, each fish harbors a single specific species of luminous bacteria.

Genetic experiments performed in conjunction with Dr. Irving C. Crawford, Scripps Clinic and Research Foundation, La Jolla, California, have yielded the first genetic-map information of a marine bacterium. In another study, a wide array of marine bacteria capable of manganese oxidation has been isolated. Investigations of the physiology and biochemistry of manganese oxidation by marine bacteria are now under way, with the ultimate goal of elucidating the role(s) of these bacteria in the manganese cycle in the ocean.

Dr. William A. Newman and associates have been continuing work on coral reefs and benthic crustaceans. A statistical analysis of diversity trends in coral-inhabiting barnacles, in collaboration with Dr. Peter A. Jumars and Arnold Ross, substantiated the view that species-rich genera exploit a greater variety of hosts and have greater geographical ranges than genera with few species. The larger coral barnacle genera contain eurytopic, generalized forms that exploit reef-coral dominants of greater average generic age than those exploited by stenotopic barnacles. This pattern, in corals and their symbionts, indicates that modern adaptations of Willis's Law (age and area hypothesis) are applicable to the marine realm.

Ross and Dr. Newman completed the first major revision of the acorn barnacles to be undertaken in more than 60 years.

Dr. Alan J. Southward, Plymouth Laboratory, England, and Dr. Newman presented their findings on the ecology and biogeography of Central American shore barnacles at the CICAR-II (Cooperative Investigations on the Caribbean and Adjacent Regions) Symposium in Caracas. These findings refute the recent hypothesis that insolation (thermal tolerance), rather than biological parameters, accounts for the reciprocal relationship between the presence of coral reefs and the diversity and abundance of intertidal barnacles.



*Graduate student Karen F. Wishner bolts plankton net to Deep-Tow (left center), an instrumentation system developed by the Marine Physical Laboratory for towing behind a ship while carrying a variety of remotely controlled equipment for photographing, mapping, and sampling the deep ocean. Wishner's studies were conducted aboard Woods Hole Oceanographic Institution's R/V* Knorr *during an August 1975 expedition in northeast Atlantic Ocean.*

*John F. Hadley*
*Woods Hole Oceanographic Institution*

Dr. Raymond T. Bauer completed his doctoral work on the functional and evolutionary significance of grooming in decapod crustaceans, and Larry E. Ritchie, graduate student, is completing his thesis on coadaptations between a local crab and rhizocephalan barnacle. Recently initiated studies by Gary W. Lopez, graduate student, are beginning to unravel the complexities of what is apparently genetic polymorphism in the harpacticoid copepod, *Tisbe.*

Dr. Kenneth L. Smith has been developing equipment for measuring activity rates of benthic communities. Primary emphasis has been on construction and testing of a grab respirometer that is capable of measuring the oxygen consumption of sediments *in situ* and then returning the sediment samples to the surface. Experimental manipulation of the enclosed sediment community and overlying water is possible with electronically timed injection and withdrawal systems.

Measurements of respiration and nutrient regeneration of benthic communities of the continental slope (1,850 m) and continental rise (3,650 m), off the east coast of the United States, were made on two cruises in the northwest Atlantic using the Woods Hole Oceanographic Institution's submersible, *Alvin.* Both respiration and nutrient regeneration ($NH_4$) rates were significantly lower than measurements

made in shallow water (40 m) at comparable temperatures.

Studies of molecular adaptation mechanisms to such environmental parameters as temperature, hydrostatic pressure, and salinity continued in the laboratory of Dr. George N. Somero. Emphasis was placed on both enzymic and low molecular weight constituents of the cell. Comparisons of enzymes from organisms with markedly different cell temperatures revealed that the enhanced catalytic efficiencies of enzymes from cold-adapted marine species may derive from increased structural unfolding and subsequent enzyme hydration during catalysis. That is, hydration energy may be an important factor in "driving" the rates of enzymic (metabolic) activity, and in low cell temperature species this use of hydration energy may be of special importance.

Two graduate students working in this laboratory, David R. Bowlus and Paul H. Yancey, investigated the rationales for use of organic solutes as osmotic agents in marine species. Bowlus discovered that the use of free amino acids instead of high salt concentrations provides the organism with a hospitable solute environment in which to conduct enzymic reactions.

Yancey discovered that the enzymes of marine elasmobranch fish (sharks, skates, and rays) are adapted to function in the presence of the high urea concentrations present in these species.

Joseph F. Siebenaller, graduate student, in his studies of enzyme polymorphism and function in deep-sea fish and invertebrates, discovered that high levels of genetic variability exist in deep-sea species. He further discovered an adaptive functional difference in lactate dehydrogenases from two fish of the same genus which occur over different depth ranges.

In Siebenaller's studies conducted jointly with Dr. Tsaihwa J. Chow, the effects of trace metals (Pb and Cd) on different physiological functions of estuarine fish were investigated. These studies demonstrated that an accurate appreciation of heavy metal effects must include consideration of how

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environmental factors in addition to heavy metal concentration influence organism-metal interactions.

Dr. Benjamin E. Volcani and his associates are focusing on the diatom as a "reconnaissance system" for elucidating the mode of action of silicon within the cell and then testing these findings in the far more complex mammalian system.

Dr. Leslie Borowitzka, through studies of changes in cyclic nucleotide content in synchronized cultures of *Cylindrotheca fusiformis,* provided evidence that both cAMP (cyclic adenosine 5′-monophosphate) and cGMP (cyclic guanosine 5′-monophosphate) may participate in the processes of cell division involving silicon.

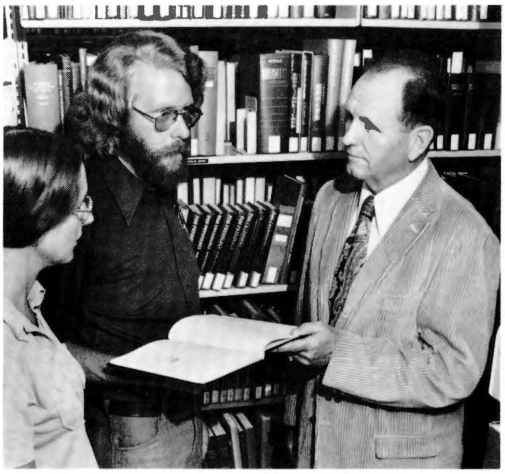
*First tour of United States by His Majesty, Emperor Hirohito of Japan (at far left with signature), included a visit to Scripps on October 9, 1975. The Emperor arrived by limousine near Sumner Auditorium, where he exchanged greetings with Director Nierenberg (at left) before faculty, staff, students, townspeople, and representatives of U.S. and foreign media. The Emperor and director went by cart to end of Scripps Pier and viewed R/V* Thomas Washington *towing FLIP (below). His Majesty, a published scientist, then met for more than an hour with biological oceanographers Drs. William A. Newman (shaking hands) and Robert R. Hessler (center), with Dr. Susumu Hagiwara of UC Los Angeles (right), translating. The Emperor autographed one of eight books he earlier had given the Scripps Library for its special collections. Examining the text are Deputy Director Merdinger (right) and Barbara Tillett and Paul Leverenz of the library.*

In studies of the fundamental fine structure of morphological variants of *Phaedactylum tricornutum,* Dr. Michael Borowitzka found that the structure of all cell types is essentially the same except for those differences caused by external cell-type morphology.

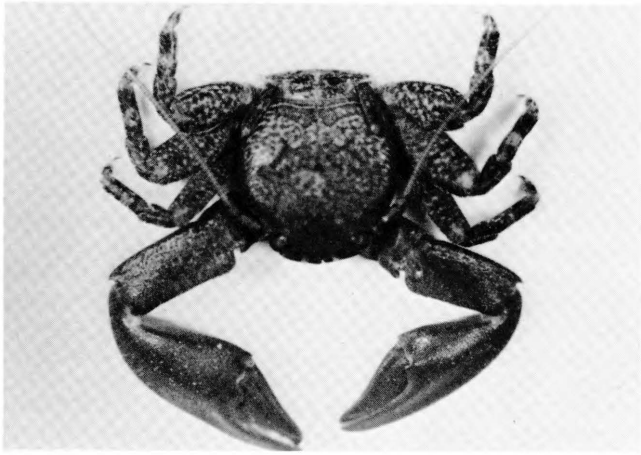
In studies of enzymes related to photorespiration in light-dark synchronized *C. fusiformis,* Dr. John S. Paul found that glycolate oxidation itself is unaffected by starvation and remains constant throughout the cell cycle. Specific enzymes involved, for example, transamination of glyoxylate and glyoxylate carboligase, however, differ in their response to light and nitrogen starvation. Dr. Paul further demonstrated the presence of an alternate pathway for glycolate metabolism.

Thomas W. Okita, a graduate student, in investigations of the role of silicon in DNA synthesis in *C. fusiformis,* has isolated and characterized at least five distinct DNA polymerase activities and has implicated two of these in silicon regulation of DNA formation.

Dr. Charles W. Mehard, following up his observation that electron-dense silicon granules occur in the mitochondria of both diatoms and rat tissues, has investigated the possibility that these silicon granules might participate in siliceous wall formation in diatoms and in promoting calcification in mammals. Through electron probe X-ray microanalysis, Dr. Mehard showed that mitochondria of *C. fusiformis,* which are close to the region of new cell-wall development, contain some Si-granules. Further studies on rat liver in mitochondria *in vitro* showed that Si uptake is enhanced under conditions that promote formation of calcium

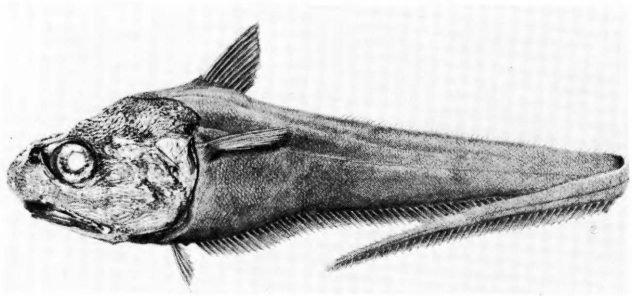



*Penpoint gunnel,* Apodichthys flavidus, *cares for her cluster of more than 800 translucent eggs that were laid in experimental aquarium tank. She will not leave them until after they are hatched, which usually takes 30 days. These polychromatic, eel-like fish, which seldom exceed about 40 cm, are the subject of studies by Donald W. Wilkie, marine biologist and aquarium-museum director. The species ranges on the Pacific coast from central California to Alaska, and occurs in intertidal and upper subtidal zones. Wilkie's research involves raising the young on controlled diets and conducting biochemical studies of skin pigments. Results of this work suggest that differences in coloration are not genetically determined, but appear to relate to the environment and diet of the juvenile fish.*



*Graduate student Larry E. Ritchie discovered that the thumbnail-sized* Petrolisthes cabrilloi *are fastidious crabs that have adapted a cleaning behavior as a specialized defense against parasitism. The crab quickly and vigorously brushes away potential invaders with a tiny pair of posterior legs. Crabs that prevent invasion, propagate; those that do not, are rendered sterile and controlled for life. (Above are close-up photographs showing two views of an infested specimen from southern California coastal waters.)*

*Larry E. Ritchie*



*Photo/drawing of a new genus of Macrouridae, discovered by Dr. Carl L. Hubbs. The fish is one of the few of its type living in the bathypelagic habitat, and is now being described and named by Drs. Hubbs and Tomio Iwamoto, assistant curator of fishes, California Academy of Sciences. The species was first found off the southern California coast in 1960 by a former student of Dr. Hubbs, Fred Berry. Fewer than half a dozen adults of the species have been collected in the world.*

*Drs. Carl L. Hubbs and Tomio Iwamoto*

phosphate granules and that Si is incorporated into these granules.

Si-containing minerals (for example, quartz, asbestos, or talc) have been strongly implicated in a number of diseases, including cancer. Dr. Walter Desmond, of UC San Diego, in studies of the effect of monomeric and polymeric silicic acid on growth, function, and metabolism of lung fibroblasts and epithelial cells in monolayer cultures, has found that while monomeric silicate has no detectable effect, polymeric silicate produces dramatic morphological changes in subcellular organelles.

Dr. Claude E. ZoBell has continued to study the effects of deep-sea pressures on microbial reaction rates with special reference to molecular hydrogen. He has been investigating marine bacteria that liberate hydrogen from various substrates under anaerobic conditions.

Dr. Ralph E. Lewin, currently on sabbatical leave, continued his studies on the enigmatic alga *Synechocystis didemni,* which may represent a missing link in the evolution of eukaryotic green plants from photosynthetic prokaryotes.

## *Marine Life Research Group*

The Marine Life Research Group (MLRG) continued to carry out a wide range of research related to the California Current and other regions. During the second half of 1975 the triennial CalCOFI (California Cooperative Oceanic

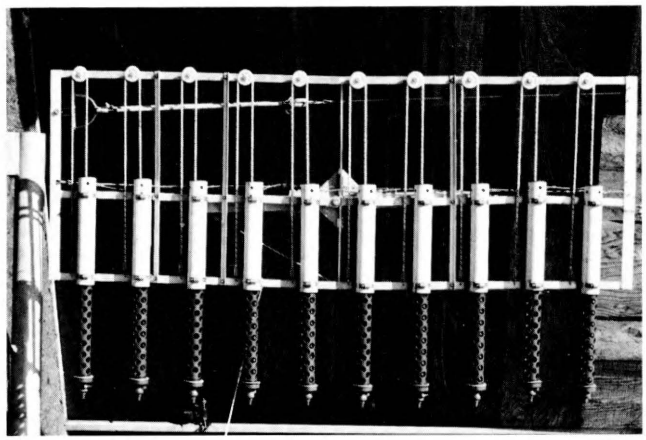
Fisheries Investigation) cruises were completed. These cruises are used to monitor the pulse of the physical oceanography and the status of pelagic fish in the California Current. In addition to taking measurements normally collected in the pelagic region, many nearshore stations were occupied. These data aided in tying the nearshore and pelagic regions together, and in improving understanding of the sport fish's relationship to the pelagic fish.

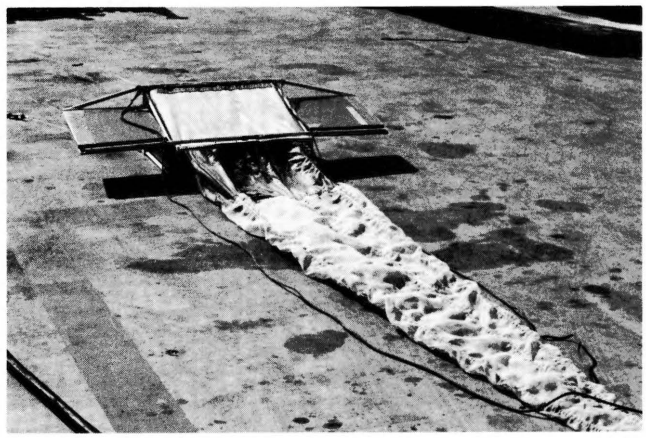
Acquisition of a new ship, primarily for the MLR program, has been approved by the university and the State of California. She will replace R/V *Alexander Agassiz,* which was acquired in 1961 from the military reserve fleet and converted by MLR for use primarily in the CalCOFI program. The new research ship should be constructed in time to participate in the CalCOFI cruises that begin in December 1977. Her research capability will be much greater than that of *Alexander Agassiz,* and this will therefore increase the types of research that can be carried out by MLR.

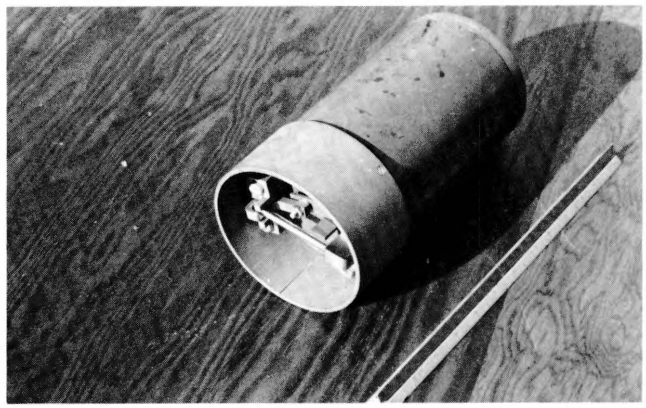
Continued cooperation with the Instituto Nacional de Pesca in Mexico City and student participation from the Escuela Superiór de Ciencias Marinas, Ensenada, Baja California, Mexico, have been an important part of the MLR cruises and of CalCOFI research in the California Current.

Last year's study of the seasonal range of sea elevation off northern Baja California has been extended to include the areas off the west coast of North America, the Aleutian Islands, and Kamchatka. Joseph L. Reid and Arnold W. Mantyla report that coastal sea elevations measured at tide gauges in the northern North Pacific show a seasonal high in winter (November-February). This high is well out of phase with the mid-ocean response of the sea-surface elevation to the heating-and-cooling cycle, which produces greatest elevations in July-October. It has been learned that sea-surface elevation near the coast varies seasonally in phase with the measurements at the tide gauges and that the high elevations in winter are a consequence of the circulation of the subarctic cyclonic gyre of the North Pacific Ocean; that is, the California Countercurrent, the Alaska Current, and the Kamchatka Current. The flow of the coastal limb of this gyre (along the eastern, northern, and western boundary of the ocean) is intensified in winter, and in geostrophic balance the sea surface slopes upward toward the coast, accounting for the winter rise. Along these coasts the sea surface stands about 14 to 30 cm higher in winter than in summer, while in mid-ocean the sea surface stands about 6 to 8 cm higher in summer than in winter. Reid and Mantyla also propose that sea elevation along the eastern boundary does not slope uniformly downward from the equator toward higher latitudes but has several maximums and minimums. These appear to be the consequence of the sea-surface slopes associated with the quasigeostrophically balanced system of cyclonic and anticyclonic gyres in high and middle latitudes and zonal flows near the equator.

Richard A. Schwartzlose continued his studies of eddies in the California Current. On *Alexander Agassiz* cruise scientists examined an eddy that was found at exactly the same location where one was discovered in 1957. While the eddy reported earlier was cyclonic, the recently discovered eddy was strongly anticyclonic. Although measurements of temperature and salinity within the first 100 m did not show the effect of the eddy, it was indicated clearly by movement of parachute drogues near the surface. At 200-400 m the temperature and salinity measurements revealed the eddy, and there were some indications of it to a depth of more than 500 m. The eddy persisted at the same position for at least three weeks. This is an area where the California Current swings shoreward and divides, part of it going into the Southern California Bight and part southward along the Baja California coast. Also, this area is a region of warmer, more tropical water pushing northward beneath the surface into the California Current.







*Pictured here are three new devices developed and successfully tested during the year by Daniel M. Brown, of the Marine Life Research Group (MLRG). As described in the accompanying MLRG section of this report, they are the decade water sampler (at top), the manta surface-skimming net (center), and the magnetic-release system (at bottom).*

*Daniel M. Brown*

Dr. William C. Patzert has continued his work with El Niño Expedition cruise data obtained off South America in early 1975. Analysis of the data confirms the preliminary evaluation that the El Niño disturbance was not confined to the surface layer, but extended as deep as 300 m. An atlas with various physical, chemical, biological, and meteorological data presentations is in preparation. Some results of El

Niño research were published in *Science*.

Evaluation of near-bottom, current-meter data obtained during El Niño Expedition has revealed a 25-day period oscillation of about 1,000 km wavelength and 4 cm/sec amplitude propagation westward at approximately 50 cm/sec. The current meters were near the equator, 300 km west of the Galápagos Islands. These characteristics agree with theoretical models of a first-mode, baroclinic, Rossby wave trapped at the equator.

During 1976, plans have been developed to initiate a long-term monitoring network in the central Pacific Ocean. This network will be a shuttle between Honolulu and Tahiti utilizing ships, aircraft, moored-current meters, drifting buoys, and island stations to monitor the low-frequency (months-to-years) fluctuations of the equatorial Pacific oceanic circulation in order to understand its dynamics. One of the ideas motivating this effort is the possibility that the tropical oceans appear to be areas in which ocean-to-atmosphere coupling may play an important role in short-term variability of atmospheric climate, particularly in the Pacific Basin.

George T. Hemingway studied the functional morphology of feeding in marine predatory gastropods. He also organized and carried out a project of collecting the plants and animals of the intertidal zone along the west coast of Baja California, Mexico. Students and faculty from the Escuela Superiór de Ciencias Marinas, Ensenada, Baja California, participated in this project.

The systematics and distribution of the deep-sea fish family Searsidae, and the young stages of two of these species, have recently been studied by Tetsuo Matsui. The larvae are large, 9-16 mm in length during the yolk-sac stage. In the two most common species from the Eastern Pacific, the length decreases from 15-16 mm to about 11-13 mm while the yolk sac is absorbed. The smaller sizes at the yolk-sac absorption stage are generally not too advanced and are emaciated. The larvae are collected over the same depth range, 300-900 m, as older stages.

In the family Searsidae, 16 genera and 22 species are recognized; three genera and four species are new. These are relatively rare fish that have been collected most frequently in areas of high productivity. It appears that oxygen content is a significant factor in the distribution of species; this is reflected in the degree of development of the gill filaments.

Examination of phytoplankton from the central North Pacific Ocean has continued. Drs. Elizabeth L. Venrick and John R. Beers and graduate student John F. Heinbokel completed a study on the effects of enclosing natural assemblages of microplankton in 250-mℓ bottles, a procedure universally employed for the determination of "simulated *in situ*" physiological rates such as primary productivity. Striking changes in the composition of the assemblages occur within periods as short as six hours. Within 24 hours most of the taxa decrease in abundance and some microzooplankton components vanish completely. An important finding of this study is that direct extrapolation of physiological measurements made on contained populations to populations in the field may not be valid.

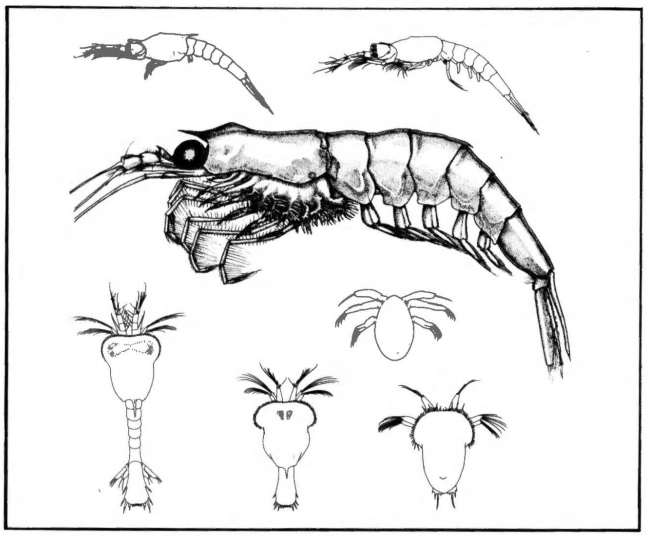
Chlorophyll and productivity measurements were taken on Indopac Expedition along an east-west transect across the Pacific. In addition to giving an increased scope to intensive measurements made at 28°N, 155°W during the past several years, the data will be used to examine the hypothesis that mesoscale and megascale eddies enhance nutrient transfer into the euphotic zone, thereby stimulating primary production and increasing standing stock of phytoplankton.

Dr. Edward Brinton and Margaret D. Knight have continued their studies of aspects of development and population ecology of euphausiid crustaceans, "krill." These include behavioral means by which such planktonic animals conserve their stocks in a drifting milieu, maintain permanent ranges, breeding grounds, and access to adequate food resources. Regions of study are the diverse, overlapping habitats of the California Current and the eastern equatorial Pacific; contiguous to the south. Here, fertile and impoverished zones and $O_2$-rich and $O_2$-deficient waters abut; however, all harbor characteristic populations. Evidently, species that undergo daily vertical migrations of several hundred meters occupy currents of different speeds and directions, whereas nonmigrating species are vertically positioned at intermediate or greater depths, so as to maintain regional stability. Different life stages appear to live at different depths. Such ontogenetic changes in habitat, vertical and regional, are being investigated with respect to development and survivorship for the more accessible euphausiid species.

The study of larval development of the three species of the genus *Euphausia* which comprise the "*E. gibboides* group" is almost complete; illustrations and description of the growth stages of *E. fallax* are being prepared, those of *E. sanzoi* and *E. gibboides* are completed. These species were studied as a group to investigate the relative importance and usefulness of an array of larval characters while providing a key to their identification in the plankton. The available descriptions of *Euphausia* larvae are for the most part based on overall size and general body plan; for example, features that may separate very different species in one area, but that may not be sufficient in waters in which similar congeners or members of a species group are found together. A detailed examination of the morphology of larval appendages and a comparison of body proportions, as well as size and form, have shown that certain features do vary consistently between species within species groups, thus permitting positive identification of early stages, usually the most difficult to separate. The identification of the larvae of *E. fallax,* which are sampled more frequently than the adults, has expanded the distribution of the species to areas within the Indian Ocean; previously the distribution was known only from southeast Asian seas.

The study of evolutionary trends in planktonic copepods as expressed by morphology, distribution, and behavior is being continued by Drs. Abraham Fleminger and Kuni P. Hulsemann. The principal approach is to test character divergence against geographical relationships among congeners in two groups of calanoid copepods, the genus *Labidocera* (family Pontellidae) and the genus *Calanus* (family Calanidae). Among a number of interesting developments during the year was the discovery of an unusually large number of speciation events within a planktonic genus occurring in the western tropical Atlantic and centering in the West Indies. The wilsoni-mirabilis lineage in the genus *Labidocera* has apparently radiated most extensively in the southern Caribbean as indicated by the finding of four new species, each from a different geographical locality within the region. Species of this lineage occupy surface waters protected from extensive offshore advection along tropical coastlines, around islands, and over shallow offshore reefs. This particular planktonic habitat has been too sparsely sampled in the Caribbean to judge the total diversity achieved by the wilsoni-mirabilis lineage. Considering the ranges of the six species now known, however, two unique features appear to have generated the unusually high number of closely related species for so spatially restricted a region as the Caribbean. The unique features, the hydrography and a parasitic fungus, have been incorporated in a hypothesis to explain the unprecedented high diversity for a zooplanktonic taxon.

Mating in *Labidocera* was examined microscopically for the first time. Individual observations were made on about 40 pairings of *Labidocera jollae* and one pairing of



*CalCOFI (California Cooperative Oceanic Fisheries Investigations) studies by Dr. Edward Brinton's research group, Marine Life Research, include growth analyses of* Euphausia gibboides *(above), a major species of krill that inhabits the California Current. The large adult (center) is shown with six larval stages (clockwise from center right).*

*Illustrations by*
*Susan Congleton-Adult*
*Margaret D. Knight-Larval*

*Labidocera trispinosa,* both inhabiting coastal Californian waters. The observations confirmed speculations on the functioning of sexually modified morphological features in both sexes. Comparison with mating patterns in a related family provides a basis for understanding the adaptive significance of morphological differences distinguishing the two families. Sites of spermatophore attachment on the female abdomen *(Labidocera)* were discovered to be characterized by intense concentrations of integumental glands. Comparisons between sets of species differing within geographical relationships showed a pattern of interspecific variation attesting to the importance of these glands in barriers to interspecific hybridization.

Studies on the taxonomy and distribution of *Calanus* were highlighted by resolving questions about the North Atlantic distribution of *Calanus helgolandicus.* A reproductively active population of *helgolandicus* was found in shelf and slope waters of North America living between Cape Hatteras and the New York Bight, off the east coast of the United States. This population provides a source for the previously unexplainable sporadic records of the species across the North Atlantic Drift. Comparison of North Atlantic and north Pacific *Calanus* distributions and interspecific morphological divergences indicates fundamental differences in the distribution of *Calanus* habitats in the two oceans, qualities that reflect differences in the circulation patterns of high fertility waters of the mixed layer between the two oceans.

Information on the marine environment recorded in varved anaerobic sediments off the west coasts of North America and South America is being examined under John D. Isaacs' direction by Andrew Soutar, Dr. Stanley A. Kling, and Peter A. Crill. In such accumulations where disturbance by burrowing organisms is essentially lacking, a faithful time series of biological and geochemical variables can be resolved to approximately annual scale. Past work has shown that climatic information expressed in such measurements as temperature and rainfall is reflected by physical characteristics (for example, variations in sediment thickness) and the flux of biological remains (fish scales, foraminifera, radiolarians, diatoms, and coccoliths). Man's impact on the environment has been imprinted via trace amounts of various chemicals; for example, mercury, lead, and halogenated hydrocarbons. Such results suggest inquiry into the sedimentary record for clues to understanding the present environment. The cumulative nature of the record aggregates seasonal fluctuations in a way not practically obtainable by conventional shipborne sampling techniques. Comparison of cores from the Santa Barbara and Santa Monica basins, off the California coast, for example, reveals a biological imprint characteristic of each basin. A locally characteristic dominance hierarchy in radiolarian assemblages has been consistent over the last hundred years, such that at no time has either basin come to resemble the others.

While the importance of high-resolution sedimentary records as a sampling technique becomes apparent, the limited geographic distribution of natural occurrences (a few isolated areas in the world, primarily in high-productivity regions) restricts their regional applicability. Accordingly, devices to simulate a sedimentary record are being developed. A newly designed, particle interceptor-trap is being built to acquire and preserve large samples of settling material under geochemically clean conditions. Traps are to be moored at various levels in the oceans for periods of several months and retrieved upon timed or acoustic-command release. The technique outlined could be calibrated as a device for monitoring the marine environment. Samples from an earlier prototype give results consistent with records obtained from underlying sediments.

A scanning densitometer to measure and record varve thickness from X-rays of sediment cores has been built with control functions assigned to a microcomputer. The computer is also available for other data acquisition and analysis functions. A small portable keyboard, for example, has been set up as a tally counter of virtually unlimited capacity for recording individual observations. The device has proved to be more efficient than mechanical counters, and, in addition, eliminates the time-consuming and error-introducing step of keypunching manually recorded data.

The development of new instruments as discussed above, to collect or process data for various projects, continues to be an important part of MLR. The MLR machine shop, under Erich W. Duffrin, has been working on the sediment traps and improvements in the box corers for use in the varved-sediment research.

Daniel M. Brown has developed and has in operation three new devices: the decade sampler, the manta net, and the magnetic release and actuator.

The decade water sampler was designed to measure microstructures by closing ten 450-m$\ell$ water samplers simultaneously when they are activated by a messenger. The unit is 2 m long and is deployed on a hydrographic wire. Particular attention was paid to having no contamination problems inherent in the design; thus, the sampler works essentially like a big suction gun. It was realized that an additional type of sampling might be possible with such a device; namely, the sampling of unconsolidated sediments or nepheloid layers on the bottom of the ocean. The decade sampler was thus designed to operate as part of a free-vehicle system. In the free-vehicle mode, it can go to the ocean floor, remain on the mechanical bottom for a number of hours to allow the sediments to come to equilibrium again after being disturbed by the landing of the sampler, take a sample, and return to the surface. In this manner, a closely spaced series of water and/or unconsolidated sediment samples can be taken with a known distance from the bottom.

The sampler has already yielded information on the micro-

structure of the chlorophyll maximum layer off southern California, showing it to be made up of phytoplankton layers a few centimeters thick.

The surface of the sea is under increasing study as the importance of this interface with the air has been more closely scrutinized. A surface skimming net was devised to sample this surface layer in a manner not achieved by earlier neuston-net designs. The objectives were to sample surface water quantitatively, keeping the scare effects to a minimum and being a surface follower. These requirements were met by the design of the manta net. Bongo nets, which have a 220-cm circumference, are used as the filtering part of the manta net and are towed by a frame that is steered by two paravanes to keep the net away from the ship. A special wire bridle achieves the necessary steering angle, and two wings support the frame on the surface of the water, like hydroplanes. The towing forces on the frame come from a submerged towing weight and bridle designed to keep the mouth of the net always on the water.

Catch results have yielded some surprises in the kinds of small fish and squid that have been captured on the surface, even during daylight tows.

The problem of operating instruments in deep-ocean waters is a source of constant concern. The magnetic-release system transmits the force of a magnet from inside a pressure vessel to an outside keeper, holding the keeper in place. Upon the closure of a switch inside the vessel, the magnet is made to move and release its grip on the outside keeper. A trip hook attached to the keeper then activates the desired function. Thus, the electrical systems are never exposed to the water or pressure, as they are contained in the pressure vessel. Only magnetic force is transmitted by steel bolts through the pressure wall. All the outside mechanisms are mechanical and are not affected by water or pressure.

The opening/closing mid-water trawl now uses this system, and it has eliminated all the failures that might result from leaking wires, connectors, and solenoids. The bongo net now has a new magnetic mechanism to open and close the net without use of messengers.

The release, a non-explosive device, is a much less expensive unit to use for many free-vehicle systems as it does not require careful assembly, operation, or check-out system. Even rotary motion has been transmitted through the pressure wall and has been used to govern the movement of a drum on a large sediment trap. The concept has now opened up a whole new method of activating underwater equipment.

During the past year the Ocean Technology Group, under Meredith H. Sessions, has been engaged in several programs. An improved digital-recording, free-vehicle current meter has been developed to extend the endurance of missions up to six months and overcome the data processing problems attendant to the large increase in capacity of information stored within the instrument during long-term deployments. A solid-state, flux-gate compass was developed for this instrument to remove the problems related to mechanical compasses common to present-day current meters. This current meter also incorporates hardware to permit placing the instrument in mooring lines of moderate loads without stressing the instrument.

A computer-based data reading and editing capability has been developed to permit timely reading and processing of the data recorded by current meters and other instruments that use this magnetic recording technique. This system is fully operational and permits the reading of several months of data in less than 15 minutes directly into the computer for automatic processing.

Acoustic recall of free vehicles has been developed and successfully tested. Several systems are now deployed in the equatorial Indian Ocean for durations of four months.

A low-drag flotation package and mooring system has been developed for current meter measurements in high-velocity equatorial regions. These systems are now operational on the equator.

A NORPAX program of measuring the thermal structure in the North Pacific Ocean in a north-south direction between Alaska and Hawaii utilizing U.S. Navy Fleet aircraft has been conducted for the past several years. Monthly flights between Adak Island and Honolulu and the onboard recording of data have been successfully maintained throughout the year by this group.

Instrumentation for monitoring performance of the Tethered Float Breakwater system was designed and installed in support of the bay-scale model. Data were continuously monitored over an eight-months period and automatically recorded when events of significant magnitude, such as storms, occurred. These data permitted detailed analysis of actual sea performance of a large, scale-model array.

In addition to the breakwater monitoring program, a general low-cost wave monitoring network was conceived using the hardware developed for the breakwater program. Four stations were installed in the ocean between Oceanside and Imperial Beach, California, with data being automatically recorded twice daily at Scripps's central computer site. This information is computer-processed and disseminated on a monthly basis to interested agencies. The system is highly automated and designed to demonstrate the feasibility and economics of operating a network that can be expanded to provide very large area coverage.

## *Marine Physical Laboratory*

Understanding the effects of the ocean and its interfaces on the generation and propagation of acoustic energy continues to be the principal goal of the Marine Physical Laboratory (MPL). The research areas include studies of the variation in sound propagation caused by oceanic parameters, signal processing, observation of oceanic phenomena and the ocean bottom with acoustics, and development of ocean technology.

Dr. Fred N. Spiess, director of MPL, returned from a 15-months tour as a member of the scientific liaison staff of the Office of Naval Research Branch Office, London. Dr. Victor C. Anderson served as acting director during Dr. Spiess's absence. Since Dr. Speiss's return, he has worked on the improvement of the capabilities of the Deep-Tow instrumentation, and the planning of scientific cruises, including Leg IV of Pleiades Expedition to conduct fine-scale observations of the deep Pacific manganese-nodule fields.

Daniel K. Gibson and his group have reached the final stages of development of a large-aperture acoustic receiving array, otherwise known as ADA (Advanced Detection Array). This acoustic system will use signal processing and beamforming concepts developed at MPL to make advanced measurements of the statistical directional properties of the background noise field in the ocean. First sea tests of this novel instrument are scheduled for November 1976.

Dr. Frederick H. Fisher has continued to explore the multipath arrivals of acoustic energy in the ocean, using the vertical array of hydrophones deployed from R/P FLIP (Floating Instrument Platform). In two deep-water tests off southern California, studies were made of the fluctuation of the discrete sound paths as a function of range and array depth. In another project, using the 87.5 kHz sonar on FLIP, Dr. Fisher studied the distribution of minute scatterers of sound in the multiple horizontal layers throughout the upper levels of the deep ocean. In the laboratory ashore, Dr. Fisher's work included the study of the effects of pressure on the electrical conductance of seawater salts and the absorp-

tion of sound in seawater resulting from pressure-dependent chemical reactions involving magnesium sulphate and boric acid.

Sea-floor studies using the improved Deep-Tow instrument have continued under Dr. Spiess's guidance. The addition of water-sampling capability, extension of acoustic data acquisition, and improvement of photographic illumination have all increased the instrument's value to science. In late summer 1975, the group, led by Drs. John D. Mudie, Carl D. Lowenstein, and Peter F. Lonsdale, participated in the Natow Cruise aboard Woods Hole Oceanographic Institution's R/V *Knorr* in the North Atlantic, in cooperation with Dr. Tanya M. Atwater of Massachusetts Institute of Technology, Cambridge, and Dr. Charles D. Hollister of Woods Hole Oceanographic Institution, Massachusetts. The Deep-Tow instrument was used to study tectonic processes at the actively spreading Reykjanes and Mid-Atlantic ridges, and the effects on abyssal sedimentation of strong bottom currents from the Norwegian Sea. In April 1976 Pleiades Expedition, on R/V *Melville,* began with a short Deep-Tow cruise in the California borderland area, continuing U.S. Geological Survey's work in this region, which is directed toward the discovery of offshore resources and identification of environmental problems in their exploitations. The Deep-Tow observations were directed particularly toward recognizing active earthquake faults in the sea floor adjacent to possible offshore pipeline routes.

This work was followed by a cruise, led by Dr. Lonsdale, to the fast-spreading crests of the East Pacific Rise at 3°S and the Galápagos Spreading Center at 86°W. In addition to tectonic studies, the Deep-Tow system was used here as a geochemical sensor, "sniffing" for evidence of deep-sea hydrothermal emanations. A CTD (Chemical/Temperature/Depth) instrument was attached to the vehicle, and this successfully identified plumes of warm water rising from fissures in the young volcanic rock. Samples of these plumes were obtained by water bottles attached to the vehicle. Some of the several thousand color photographs taken with the Deep-Tow cameras at the spreading centers show that the fissures from which warm water emanates are surrounded by patches of brightly colored sediment, believed to be precipitates from the hydrothermal solutions.

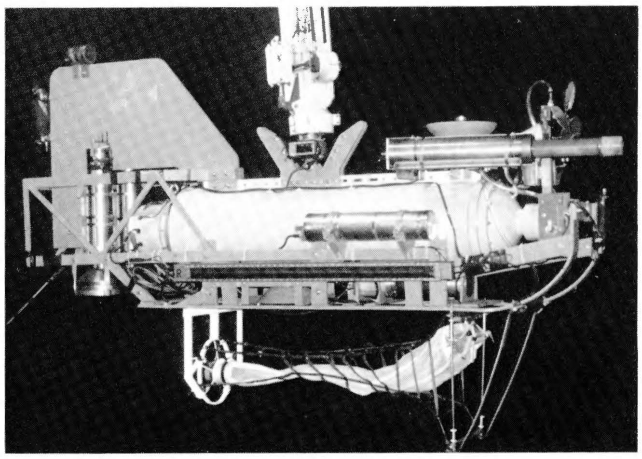
Working under Dr. Anderson's guidance, Brett Castile has conducted several observations at sea aboard R/P ORB (Oceanographic Research Buoy), using high-frequency transducers to study the characteristics of biological scatterers in the upper layers of the ocean. Also with Dr. Anderson, the group under Dr. G. Thomas Kaye continued study of the specular reflection of sound from oceanic temperature layering. The work of Drs. Fisher and Kaye and Castile, using different sensors at different frequencies and with different signal processing to observe the nature of the scatterers of acoustic energy in the ocean, is providing the basis for an integrated program.

Dr. George G. Shor, Jr., and William Whitney have continued the analysis of data obtained from the propagation of very-low-frequency energy through the sea floor during cruises in the mid-Pacific region. Their research continued during participation in Indopac Expedition, an investigation of the nature of the crust beneath the sea floor in the marginal basins of the western Pacific Ocean.

Dr. Lawrence A. Lawver participated in the expedition, conducting a heat-flow measurement program to study tectonic problems arising from interaction of the Australian and Southeast Asia plates.

Victor Vacquier continued his studies of terrestrial heat flow and its relation to tectonics and the maturation of petroleum. His work in the oil fields of Brazil has led to formulation of a plan for investigations of the heat-flow regime of the subduction zone of the Indonesian island arc.

*Developmental engineer Daniel K. Gibson (at right), of Marine Physical Laboratory (MPL), describes MPL's deep-sea equipment to two representatives of Royal Thai Navy's Hydrographic Department, Bangkok, Vice-Admiral Siddhi Surakkhaka, Department Director (second from right), and Captain Viphatana Bhumisawasdi (at left); and Associate Director George G. Shor, Jr. In foreground is starboard side of MPL's RUM (Remote Underwater Manipulator), with one of its two "eyes," a mounted television camera.*



*Versatility of Deep-Tow instrumentation system, development of which began in 1960 by Marine Physical Laboratory, is indicated by addition of remotely controlled plankton net for deep-ocean biological sampling, shown in position beneath Deep Tow. Improvement of Deep Tow's photographic illumination capability and extension of its acoustic data acquisition potential also were evident during the year.*

*Marine Physical Laboratory*

Dr. Russell W. Raitt has continued his studies of velocity anisotropy in the ocean basins, including participation in the Indopac Expedition aboard R/V *Thomas Washington.*

Dr. Gerald B. Morris analyzed the large quantity of data obtained from previous cruises aboard FLIP, which used the deep vertical array of hydrophones. One report highlights the distinctive acoustic signature and the high noise level produced by a large supertanker. Other work has been

directed at measuring signal propagation losses in the ocean, particularly the frequency-dependent attenuation of sound, at frequencies from 50 Hz to 400 Hz.

Dr. Robert Pinkel has conducted further studies of the internal wave structure of the upper ocean using the 87.5 kHz sonar in FLIP's horizontal mode of operation to observe the Doppler shift of acoustic reverberation from distant water masses. While yielding valuable data on the characteristics of internal waves, the simple pulse transmitted by this sonar limits the range and velocity resolution that can be obtained. Dr. Pinkel's group is developing a new pulse-compression sonar for tests.

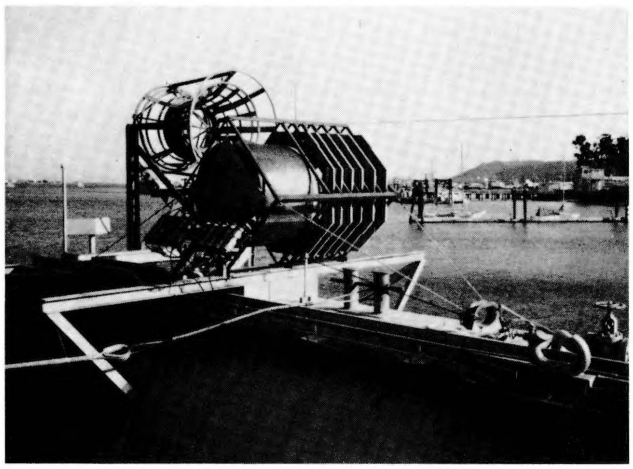
Dr. Robert Rasmussen completed a companion project to that of Dr. Pinkel's in which he investigated the use of a high-frequency Doppler sonar with a pulse-compression signal code to measure localized turbulence cells in the ocean.

Gibson's group has continued to assist Shell Oil Company with the development of the Shell Pipeline Repair Vehicle (drawing upon the technology that was developed for RUM [Remote Underwater Manipulator]), principally in the areas of umbilical cable design, power transmission and control, cable telemetry, vehicle sensors, and acoustic systems.

Dr. Lowenstein and the Deep-Tow group under Dwight E. Boegeman and the Equipment Development Group under William L. Davy have been providing technology-transfer support to other groups working or entering the deep-ocean floor search and survey field, including U.S. Geological Survey, Naval Oceanographic Office, and Jet Propulsion Laboratory of the California Institute of Technology, Pasadena. This effort has been principally in the areas of sensor technology, sea-floor acoustic navigation, and vehicle handling and control.

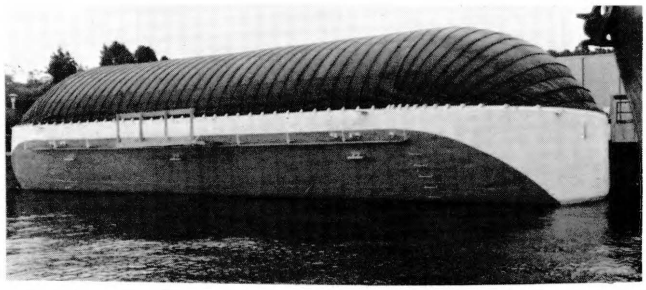
Research work continued at Southwest Regional Calibration Center of the National Oceanographic Instrumentation Center on the acoustic properties of materials and on sound absorption. The center was disestablished as of June 30.

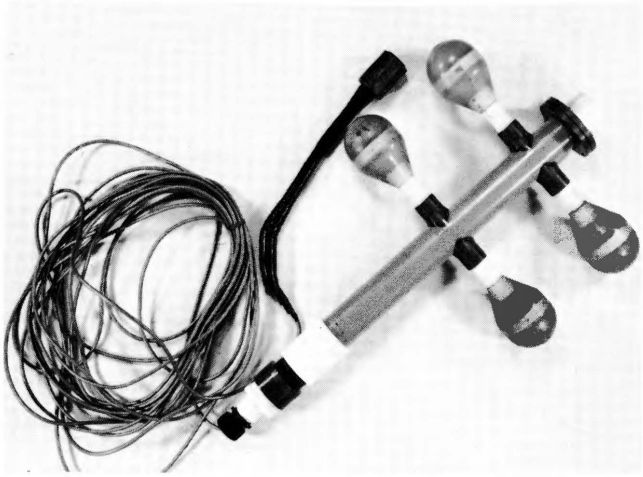
The versatility of the acoustic-calibration barge facility at Lake San Vicente has been increased by the development and installation of a transducer array lowering-and-operating system that can handle up to 1,363 kg. The system comprises 3-m sections of 5-cm steel pipe supported by a gimbal system with a telescopic sight for optical reference. Sixty calibration runs have been made with full reliability, to



*Utilizing this 87.5 kHz sonar (narrow-beam echo sounder) attached to R/P FLIP, Dr. Frederick H. Fisher studied distribution of minute sound scatterers in multiple horizontal layers throughout upper levels of deep ocean.*

*Marine Physical Laboratory*





*Submersible barge housing Marine Physical Laboratory's (MPL) novel, large-aperture acoustic receiving array, also known as ADA (Advanced Detection Array), is berthed here at Nimitz Marine Facility. Sea tests of ADA are scheduled for November 1976. Sea-going operations call for array to be towed to its work station astern of MPL's ORB (Oceanographic Research Buoy) in upside-down position from that pictured here. On station, barge will be submerged, rotated through 90°, and suspended between ORB and the ocean bottom. Array will utilize MPL-developed signal processing and beamforming concepts to make advanced measurements of statistical directional properties of background noise field in the ocean. ADA measures 21×8.8×6 m and weighs 60 tons. Hydrophone "tree," one of 720 in array, is shown in accompanying photograph. Electronics equipment is contained in pressure hull seen in third photograph.*

*Marine Physical Laboratory*

examine the farfield beam pattern of an acoustic array that weighs 835 kg in air.

In late spring, MPL moved its electronics laboratories and its equipment development and machine shops to a building that had been modified with funding support of the Office of Naval Research into an integrated Ocean Engineering Support Facility, having ready access to pier facilities of the Naval Undersea Center and the adjacent Nimitz Marine Facility of Scripps.

The performance requirements and physical dimensions of some of MPL's instrument packages provide a considerable challenge in ocean engineering. MPL's novel contributions to marine technology, which include FLIP, RUM, ORB, Deep Tow, and SCAR, are being joined by the $21 \times 8.8 \times 6$-m, 60-ton ADA vehicle now under construction.

As with all Scripps faculty and staff members, those at MPL continued to provide expertise to various national and international scientific and educational organizations and federal agencies. Senior MPL members interacted with, among others, the National Academy of Sciences, the National Academy of Engineering, the National Science Foundation, the U.S. Energy Research and Development Administration, the United Nations Educational, Scientific, and Cultural Organization, the Department of Commerce, the Department of the Interior, the U.S. Maritime Administration, the Acoustical Soceity of America, the American Geophysical Union, the Institute of Electrical and Electronics Engineers, the Marine Technology Society, and various committees and functions of the U.S. Navy.

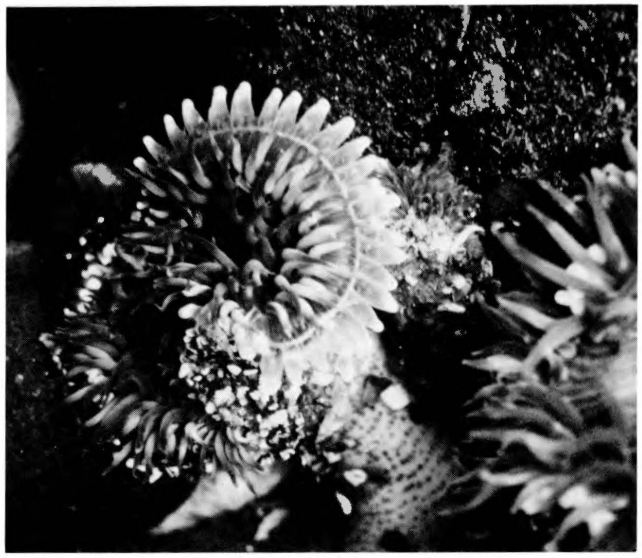
## *Neurobiology Unit*

This group comprises one of the bridges between Scripps and the UC San Diego School of Medicine and investigates a range of problems from the ethology of lower vertebrates to higher nervous integration in mammals. Sensory processing leading to behavior is a common theme.

Dr. Lisbeth Francis, UC San Diego, investigated intraspecific aggression and cooperation in the two forms of the anemone *Anthopleura elegantissima.* The clonal form lives in dense groups, and anemones at the borders between such groups engage in aggressive encounter with their neighbors. They recognize individuals from foreign clones by contact and are specialized as warriors, having more and larger weaponry than their clonemates away from the battle zone. They also lack reproductive organs. Individuals of the solitary form attain much larger size and react aggressively to contact with all conspecifics.

Studies of shark senses continue to occupy several members of the unit, particularly the reception of feeble natural electric and acoustic signals. The first recordings from the brain of responses evoked by sounds have been made and mapped in the hindbrain, midbrain, and forebrain by Dr. Theodore H. Bullock and graduate student Jeffrey T. Corwin. Corwin has tagged the sense cells with radioactive amino acids and together with visiting Dr. S.O.E. Ebbesson, University of Puerto Rico, began to work out the pathways in the brain. Dr. Ebbesson and collaborators used a battery of new methods called "experimental neuroanatomy" to map pathways and centers for visual, electric, and other functions in a number of fish and other lower vertebrates.

Dr. Ebbesson has learned that sharks and rays in general have larger brains for their body weight than most bony fish, amphibians, or even reptiles. In some rays, the brain-weight to body-weight ratio overlaps that of mammals. It cannot be concluded that these cartilaginous elasmobranchs are highly intelligent, but this and other data (physiological) suggest that they are doing a lot more with their brains, especially the cerebellum and cerebrum, than is presently appreciated.



*Two photographs show the common colonial anemone on local intertidal rocks. In one, two colonies maintain a no-man's land between them by mutual aggression between the individuals at the margins. The second picture, a close-up of the solitary form, shows two anemones engaging in intraspecific aggressive behavior. The white-tipped organs are specialized weaponry used only in such encounters.*

*Neurobiology Unit*

Fish that detect weak electric currents, from small electric organs of their own or their neighbors', or from the gills of their prey, or from the physical environment, include electric fish and nonelectric catfish, sharks, rays, and others. Drs. Bullock, Konstantian Behrend, Walter F. Heiligenberg, Rocco A. Bombardieri, Jr., and Albert S. Feng, and graduate students Eric I. Knudsen and Terry A. Viancour continue to study aspects of electrolocation and electrocommunication. The first means the recognition of objects, boundaries, spaces, and directions, either passively or actively (analyzing the fish's electric discharge field). It has been found that the capacitance of objects, in parallel with the resistance, can be detected and estimated by some electric

fish. The filter properties of the specialized receptors have been quantified; evidence has been obtained that receptor-cell activity functions like a resonance to tune the cell sharply to a "best frequency." Brain centers specialized for analyzing electroreceptive input, especially in the cerebellum and midbrain, have been found and characterized. The midbrain centers are homologous to the auditory lobes of man's midbrain. The cerebellum contains a low-frequency, band-pass filter, which working in conjunction with the midbrain-controlled "jamming avoidance response," helps these fish to avoid being electrically "blinded" by jamming.

Dr. Dietrich L. Meyer and collaborators found a new postural control system in certain species, the Ventral Substrate Response. This response is superimposed on the long-known Dorsal Light Response and the responses to the organs of balance in the ear. The signals of light direction, of substrate angle, and of gravity come together in the floor of the brain stem to determine the posture. Specialization in certain species, which alters the relative coupling functions in this system, brings about the bizarre postures of upside-down catfish, head- or tail-standing fish, and flatfish. Evolution from lower to higher vertebrates has altered not only the anatomy but the physiology of the dependence of posture upon the several sense organs of the two sides.

Drs. Robert C. Eaton, Bombardieri, and Meyer analyzed high-speed cine films of startle responses in many species of fish, allowing conclusions about the part played by the classical giant cell of Mauthner. Dr. Eaton continued embryological study of the developing synapses on this cell.

Dr. James T. Enright has found that a single two-hour treatment in a wave simulator can reset the circadian rhythm of crustaceans and add a new persistent component to the daily pattern of activity. An elaboration on Dr. Enright's work can be found in the Ocean Research Division section of this report.

Drs. G. David Lange, Ann C. Hurley, and Peter H. Hartline continued the study of *Nautilus.* They analyzed pupillary reflex, gravistatic reflex, and electrophysiological records made on R/V *Alpha Helix.* Pupillary responses are similar to those in humans, except that all relevant time constants must be multiplied by a factor of about 100. Similarly, the electroretinogram is slow compared to that seen in squid and octopus. Control of eye position with respect to gravity seems to be solely by the ipsilateral statocyst organ.

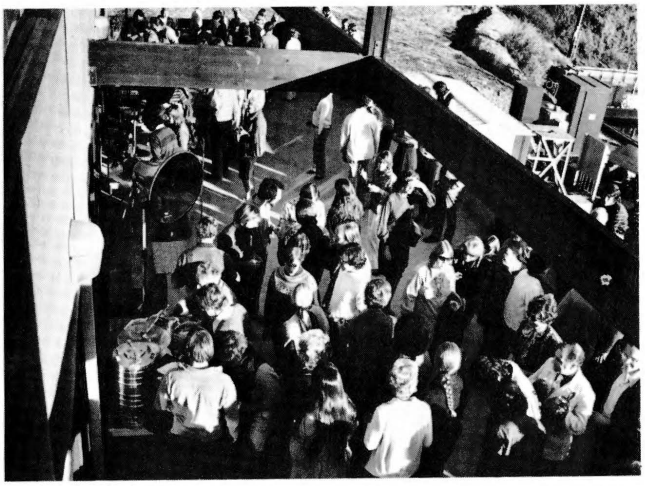
## *NORPAX*

NORPAX (North Pacific Experiment), a multiinstitutional program sponsored by the National Science Foundation and the Office of Naval Research, is headquartered at Scripps. Thirty-three scientists from 12 universities are studying the large-scale fluctuations in the thermal structure of the Pacific Ocean from 20°S to 60°N and their relation to the overlying atmosphere. Achievement of this goal should eventually lead to the ability to predict the thermal structure of the upper layer of the Pacific Ocean and to improved weather/climate prediction for both the northeast Pacific Ocean and North America. Attainment of this goal is clearly years away.

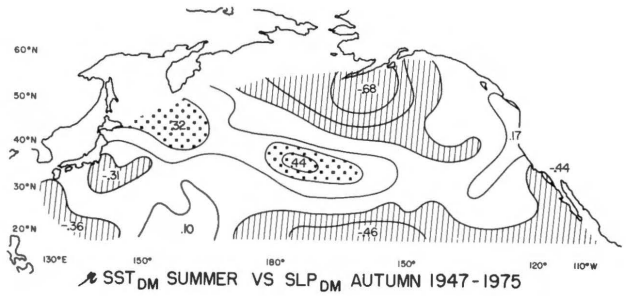
Two major areas of research are being explored at Scripps: (1) statistical/analytical studies of the ocean and the atmosphere and their interactions, and (2) the monitoring of the thermal structure of the upper layer of the Pacific Ocean.

Dr. Jerome Namias has identified a negative air-sea feedback relationship between summer sea-surface temperature anomalies in the area south of the Aleutian Islands and the subsequent fall sea level and upper level pressure in the Aleutian Low area. For instance, abnormally warm summer temperatures lead to strengthening of storms and a shifting of the storm tracks; these, in turn, tend to reverse the temperature anomaly pattern. NORPAX Figure 1 (*q.v.*) indicates the strong ($p<.100$) negative correlation of summer sea-surface temperature anomaly centered at about 50°N-160°W with subsequent fall sea level pressure anomaly. The effects of summer sea-surface temperature in the Aleutian area have been correlated with United States weather patterns a season in advance. As an example, NORPAX Figure 2 shows that warm summer sea-surface temperatures in the Aleutians tend to be indicative of a warmer than normal fall in the western United States, but colder than normal in the southeast.

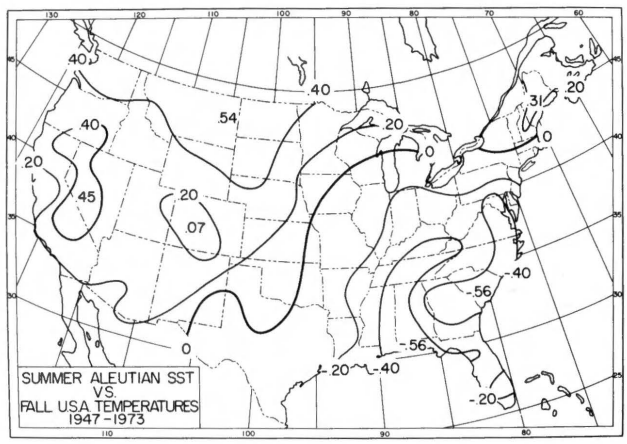
The El Niño phenomenon, characterized by abnormal warming of the ocean off the western South American coast, appears to be associated with an appreciably weakened atmospheric high-pressure cell over the eastern third of the North Pacific during the preceding year. This lends support to the theory that generation of El Niño is a long-term, large-scale process in which reduced wind stress permits an accelerated equatorial countercurrent and diminished equa-



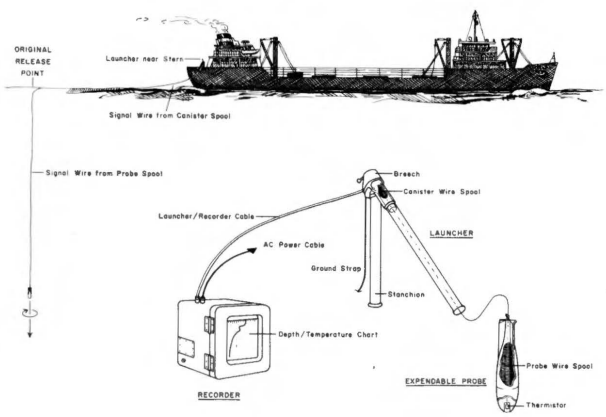
*A new building to house most of Scripps's physical oceanographers was completed during the year. The $605,000 structure, shown above, has a grid work of 6-m, 15×15-cm beams which now gives a geometric effect, but will be used to support future expansion of the upper level. The facility, called the NORPAX/Physical Oceanography Building, now provides 1,100 m² of assignable space. Lower photo was taken during building dedication festivities.*




*NORPAX Figure 1 (see text)*




*NORPAX Figure 2 (see text)*



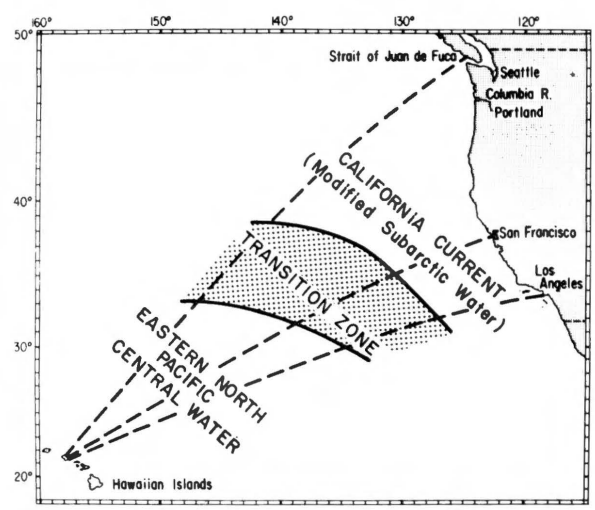

*NORPAX Figure 3 (see text)*

torial upwelling. Dr. Namias has applied statistical dynamical models to data from the 1950-1970 period. They indicate that fluctuations in the inferred heat transport of the North Equatorial Countercurrent are strongly related to *subsequent* variations of ocean temperature in the eastern equatorial Pacific (El Niño). Changes in sea-surface temperature in the equatorial mid-Pacific follow by six months similar changes off the west coast of South America. This suggests the importance of westward advection by the mean flow or Rossby waves in the heat budget of the equatorial mid-Pacific. It was also learned that changes in the local wind field off Peru have little relation to El Niño.

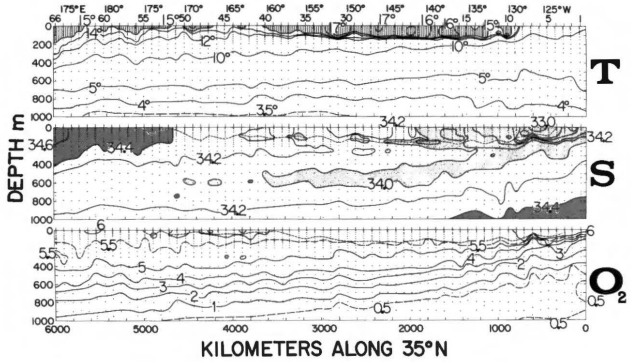
The upper layer of the mid-latitude Pacific is being monitored by four interrelated efforts at Scripps. The first two programs utilize observations taken by merchant ships with expendable bathythermographs (XBT) as shown in NORPAX Figure 3.

In the first of the programs, Scripps cooperates with the National Marine Fisheries Service and the U.S. Navy Fleet Numerical Weather Central, Monterey, California, to obtain and analyze temperature sections of XBT observations taken by merchant ships on routes between Hawaii and three United States west coast ports (Seattle, San Francisco, and Los Angeles, as shown in NORPAX Figure 4). The San Francisco section, which has been in operation for ten years, constitutes the world's only consistently monitored subsurface temperature section in the open ocean. This region comprises three important oceanic regimes: cool, low-salinity, modified, subarctic waters of the California Current; a complex Transition Zone; and warm, high-salinity, central waters of the eastern North Pacific. Research studies by J. F. Theodore Saur are directed toward defining and understanding season-to-season and year-to-year changes of surface temperature and salinity, subsurface temperature structure, heat storage in the upper layers of the ocean, location and character of oceanic fronts and of boundaries between water masses, and oceanic circulation.

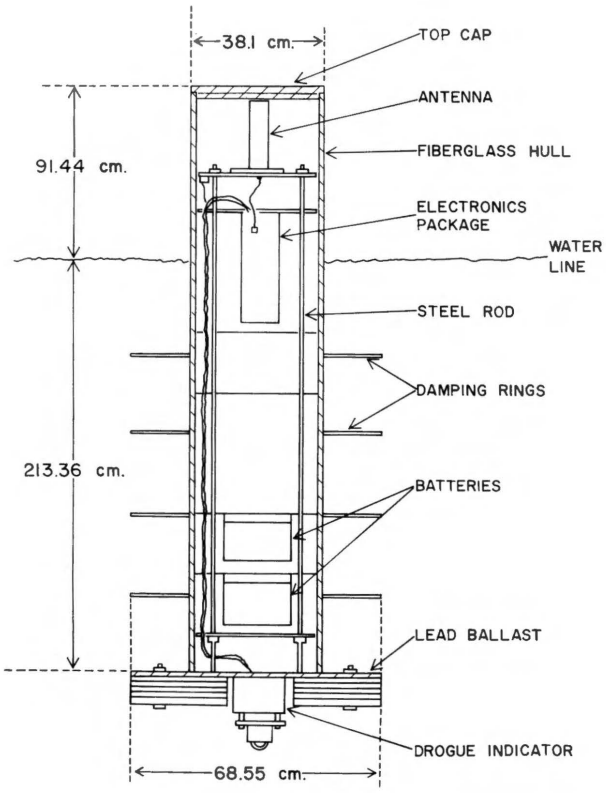
Recent analysis of historical data indicates that year-to-year variability in sea-surface temperature in the mid-latitude North Pacific is associated with major changes in the general circulation of the upper ocean. Therefore, the understanding of the former has led to the development of a second large-scale thermal monitoring program called TRANSPAC, directed by Drs. Warren B. White and Robert L. Bernstein. This program is designed to map the changes in the upper ocean's general circulation over the entire mid-latitude North Pacific on a month-to-month basis for at least a decade. The way this is done, using 25 ships-of-opportunity (commercial ships outfitted with XBT systems) that ply the seas between the west coast of the United States and Japan, is unique and represents the first attempt of oceanographers to make observations of the ocean in a fashion similar to the weather monitoring system that has existed over the United States for




*NORPAX Figure 4 (see text)*



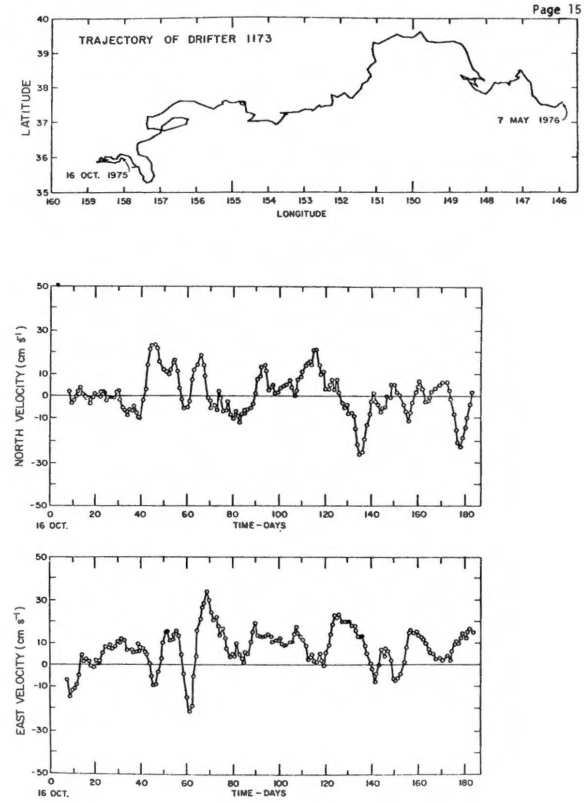

*NORPAX Figure 5 (see text)*




*NORPAX Figure 6 (see text)*

the past 40 years. It is expected that this continual, broad, updated coverage of the general circulation will significantly increase knowledge of how general circulation in the central ocean behaves. It also represents the first attempt to provide the broad data coverage required to verify the many large-scale general circulation models, which have been in existence now for over a decade.

Evidence from this thermal network suggests the following: sea-surface temperature anomalies are associated with large-scale meanders in the otherwise quasi-zonal flow (North Pacific Current) at mid-latitude; those meanders in the upper-ocean general circulation are primarily generated by year-to-year variability in the autumn/winter storm forcing; and the meanders are not stationary, but appear at times to move either east or west.




*NORPAX Figure 7 (see text)*

The dynamics of this meander behavior in the North Pacific Current is being investigated with the use of general circulation models at Scripps and the U.S. Naval Postgraduate School, Monterey, California, the latter under the direction of Dr. Robert L. Haney.

The third monitoring program involved a detailed hydrographic section carried out by Dr. Kern E. Kenyon along 35°N between California and Japan to test a hypothesis that arose out of other NORPAX work. The section, which was the most extensive east-west hydrographic survey ever carried out in the North Pacific, was the first leg of Indopac Expedition on R/V *Thomas Washington.* Ninety-eight equally-spaced stations were made with measurements extending to 1,000 m at all stations, and to the bottom at more than one-third of the stations. Underway measurements were carried out between all pairs of stations; these included continuous records of surface temperature, magnetics, gravity, and water depth, and about 600 XBT drops. Although the major program was one of physical oceanography, chemical, biological, and geophysical programs were also conducted. Samples obtained on stations are being processed for a variety of parameters, including temperature, salinity, density, oxygen, and carbon dioxide.

Climatological sea-surface temperature data show an unexplained large-scale variation with longitude; these appear from all available information to be a real and permanent feature at mid-latitudes in the North Pacific. The hydrographic cruise was designed to test the hypothesis that the longitudinal surface-temperature variation is one manifestation of a mechanism of large-scale net poleward heat transport in the open ocean. A preliminary analysis of part of the data shown in NORPAX Figure 5 indicates that the measurements obtained are consistent with this hypothesis. The

results from this study may have implications for the near-surface circulation of the North Pacific and possibly also for the climate of North America.

The use of drifting buoys to measure ocean currents is an old and widely used technique. However, the launching of the NIMBUS 6 satellite with its Random Access Measurement System (RAMS) brought this technique into the "space age." Buoys equipped with a rather inexpensive transmitter designed to communicate with the RAMS satellite can now be located to within $\pm 5$ km anywhere in the world's oceans at least once a day. Seven drift buoys designed and built by Gerard J. McNally were equipped with a RAMS transmitter (NORPAX Figure 6). These were deployed in the North Pacific as part of the NORPAX work with Dr. A. Dennis Kirwan, Jr., Texas A&M University. NORPAX Figure 7 shows a typical buoy trajectory and its associated components of velocity over a six-months period in the northeast Pacific.

## *Ocean Research Division*

Within the Ocean Research Division, many varied research projects are carried out in biological oceanography, marine chemistry and geochemistry, geophysics, and physical oceanography. The following paragraphs delineate some of this research.

Dr. Robert S. Arthur continued the development of a syllabus for a course for nonphysical oceanographers on principles and applications of dynamical oceanography. Revisions have been made in earlier sections as a result of classroom experience, and first drafts and additional sections have been completed.

Investigations of the geochronological, biochronological, and paleotemperature applications of amino-acid racemization were continued by Dr. Jeffrey L. Bada's group. Numerous fossil-bone samples were analyzed and dated on the basis of the extent of their aspartic-acid racemization. Dated samples included bones from the Cave of Arago, in the French Pyreenes; human-bone samples from sites on Mt. Carmel, Israel; bones from caves in Czechoslovakia; and samples from numerous sites in Africa. One particularly interesting study involved the analysis of a dog jawbone from the Cave of Palegawra in Iraq. This bone is thought to be from the oldest example of the domesticated dog in the world. The jaw was too small to be dated by $^{14}C$ and its age had been estimated by stratigraphic association. Preliminary amino-acid analyses suggest the bone is at least 10,000 years old, thus indicating that the dog is one of the oldest domesticated animals in the world.

Numerous analyses were also carried out on various paleo-indian skeletons from California. Several other skeletons from southern California and one from northern California have been dated at 40,000 to 50,000 years, according to the extent of their aspartic-acid racemization. These dates, coupled with those published earlier, demonstrate that man populated the New World considerably earlier than 20,000 years ago, the time that American archaeologists previously thought man first migrated into the New World.

One particularly interesting site in which numerous paleo-indian skeletons have been dated is W-12, located at the residence of the UC San Diego Chancellor. Analyses of skeletons, obtained from the San Diego Museum of Man and excavated from W-12 over the last 30 to 40 years, indicate that there were three different occupational periods represented at the site: one approximately 8,000 years ago, the second approximately 15,000 to 20,000 years ago, and the third 40,000 years ago. Inspection of the W-12 site by Dr. Bada and Pat M. Helfman, UC San Diego graduate student,

*Dr. Jeffrey L. Bada (center) and graduate students Pat M. Helfman and Edward T. Peltzer of UC San Diego and Scripps, respectively, examine front leg fossil bone of Pleistocene horse. In pan are additional parts of the ancient horse. Dr. Bada discovered the fossils in a seaside cliff adjacent to the Scripps campus. The leg bone was dated at about 50,000 years by using an amino-acid dating process developed by Dr. Bada. Carbon-14 dating of charcoal taken from near the horse bones yielded an age of greater than 40,000 years, the limit of the carbon-14 technique. Dr. Bada's process has dated human fossils from the San Diego area at nearly 50,000 years, more than twice the previously recorded New World dates.*

indicates that substantial parts of the site have remained undisturbed. Thus, during the summer of 1976, work will begin on excavating this potentially important paleo-indian site.

Work has also been carried out on the racemization of aspartic acid in living mammals. Based on the rate of racemization of aspartic acid in geological samples, scientists predicted that asparctic-acid racemization should also take place in living mammals in proteins that are not regenerated during their lifetime. To test this, analyses were carried out on tooth enamel and dentine extracted from human teeth from donors of various ages. The results indicate that with increasing human age, there are increasing amounts of D-aspartic acid present in human teeth. The rate of racemization in human tooth dentine can be expressed by the equation

$$\mathrm{Ln}\ \{1 + D/L\} = 7.87 \times 10^{-4} yr^{-1} \cdot t + 0.014$$

where t is the age of the tooth in years.

This equation can be used to estimate the age of any long-lived mammal, provided a suitable tooth can be obtained. Thus, just as racemization of amino acids provides a useful tool in dating fossil materials, it may also develop a similar function in "biochronology." Probably the most interesting application of the above equation would be to examine claims of unusual longevity among peoples living in Ecuador, the Hunza region of India, and the Georgian Soviet Socialist Republic, as some doubt has been raised about the authenticity of the centenarians. Verification of extreme longevity, using the aspartic-acid racemization in human teeth, would

be of considerable importance to gerontological research. Moreover, it may be possible to construct age profiles of natural populations of long-lived mammals. To test this, preliminary analyses have been carried out on spotted-dolphin teeth, sperm-whale teeth, and various other mammal teeth.

Another application of amino-acid racemization that has been investigated involved the use of this reaction to estimate geothermal gradients in deep-sea sediments. Analyses of various core samples brought up by the Deep Sea Drilling Project indicate that racemization of amino acids in foraminifera which have been dated by some independent technique, can be used to estimate accurately heat-flow values for various oceanic areas. Results obtained by this method provide average heat flows over several hundred meters of sedimentary thickness and are thus potentially much more reliable than heat flows obtained by temperature probes, which penetrate only the first few meters of the sedimentary columns.

Studies were also carried out on amino acids dissolved in various oceanic waters. Results indicate that free amino acids are present only in minute quantities in surface waters of the ocean and are essentially absent in deep waters. Combined amino acids, on the other hand, have been found to have a concentration of approximately 200 to 400 nanomoles per liter in oceanic surface waters and approximately 100 to 200 nanomoles per liter in deep waters. The source of the combined amino acids may be bacterial detritus material.

Dr. Tsaihwa J. Chow continued his studies concerning the biological effects of lead on marine organisms. With the cooperation of Dr. George N. Somero, tissue-specific lead accumulation and decay rates in the estuarine teleost fish, *Gillichthys mirabilis,* were determined as a function of four variables: seawater lead concentration, duration of exposure to lead, ambient salinity, and temperature. Distinct tissue-specific accumulation rates were found. Spleen, gills, fins, and intestine accumulated the greatest amounts of lead; liver and muscle accumulated the least lead.

Decay of lead from tissues of lead-exposed fish was observed only for gills, fins, and intestine, tissues that all possess an outer or inner covering of mucus. This suggests that the rapid turnover of lead in these mucous-covered tissues may be a result of lead complexing with mucus and subsequent loss of lead when the mucous layer is sloughed off.

The rate of lead accumulation was dependent on both the holding temperature and the ambient salinity. Fish held at high temperature accumulated lead more rapidly than fish held at low temperature. The rate of lead accumulation was inversely proportional to the salinity of the medium. Both of these effects on lead accumulation rates could be significant in estuarine habitats where lead concentrations, salinity, and temperature are all apt to vary seasonally.

Dr. Chow has also studied the distribution of barium in southern California coastal waters. The present barium content of these waters was determined to be 11 to 22 micrograms per kg of seawater. These values may be used as a base line to monitor marine contamination during future offshore oil and gas explorations.

Several projects related to the ecology of kelp communities were continued by Dr. Paul K. Dayton and his group. Long-term studies of natural fluxes of important populations were continued in kelp beds off Catalina Island and Point Loma, California. The intensive Point Loma program includes a long-term study quantitating algal mortality patterns, especially those resulting from entanglement with drift plants. Studies of hierarchies of dominance in the competition for light between several species of algae, the methods and limits of natural kelp dispersal and growth rates in different areas, and the community ramifications of the activities of various herbivores and carnivores were continued. Graduate student Brock B. Bernstein continued his thesis research on the population dynamics of several species of animals that encrust kelp fronds. Dr. Mia J. Tegner continued to explore the optimal management of local sea-urchin fisheries and their effects on the marine ecosystem.

Community interactions in various benthic associations in the McMurdo Sound area were the target of the continuing antarctic research program. The main, ongoing, sponge-community research is now directed toward the recruitment and survivorship of the sponges and their reproductive and defense adaptations. In particular, the analysis of spatial distribution patterns as influenced by depth, sedimentation, competition for primary space, and predation has been emphasized and refined. Two new studies were directed toward the ecology of encrusting communities and the ecology of soft-bottom communities. Graduate student John S. Oliver's thesis research has focused on succession and larval settling ecology.

Other graduate students' research included infaunal dynamics and predator-prey interactions in the Scripps sand-bottom community by Noël Davis and Glenn R. Van Blaricom; population dynamics of several species of cup corals by Timothy Gerrodette; micro-distribution and population dynamics of the fauna associated with large intertidal algae by Frederick C. Gunnill; and the ecology of a local invasion of *Sargassum,* a Japanese seaweed, by Lawrence D. Deysher.

Dr. Russ E. Davis and Robert Weller have been developing a new type of current meter intended to be used on surface moorings for the study of near-surface currents and their response to wind stress. Despite the seeming simplicity of the theoretical notions relating wind stress and ocean current variability, few observations are in accord with these theories and none is sufficiently complete to delineate the details of momentum transfer in the upper 100 m of the ocean.

The need for a current-sensing system capable of measuring "mean" currents in the presence of high-frequency noise from surface waves, or mooring motion, is essential to observational studies of such phenomena. Conventional rotor and vane current meters do not provide accurate current measurements in such circumstances.

During the past year, effort has been directed toward laboratory testing and at-sea trials of a Vector Measuring Current Meter (VMCM). The VMCM uses propellers to sense the components of current parallel to two orthogonal horizontal axes. Because the components of velocity are averaged and sensed directly, problems experienced with conventional meters are avoided. Laboratory tests have confirmed that this design objective was met.

The VMCM was used to observe the structure of the Pacific Equatorial undercurrent along the 150°W. Results are not yet available, but it is hoped that by combining the VMCM observations and comparison observations made by David Halpern, of the National Oceanic and Atmospheric Administration, a high-resolution picture of the zonal and meridional velocities in this unique current system will be obtained.

Dr. James T. Enright has continued his research on the behavioral physiology of marine crustaceans. A recent article documents the manner in which environmental stimuli, associated with waves on the beach, synchronize the biological "clock" of a small intertidal crustacean. A single two-hour treatment in a wave simulator has been found sufficient to "reset" the animal's timing system by several hours, the direction and amount of reset depending upon the time the animal is treated. This kind of once-only treatment can also evoke a new "component" in the activity pattern, so that the

animal will thereafter spontaneously repeat the evoked activity at successive 25-hour intervals. Such plasticity in the activity pattern indicates that the animal can be forced by the environment into a persistent daily routine, in a manner analogous to that by which human beings can form habitual daily activity patterns.

In a separate project, recently analyzed data demonstrate that small, vertically migrating copepods can sustain surprisingly high swimming speeds for intervals of more than an hour. Velocities of up to 90 m an hour have been documented for animals only 2.5 mm in length. Related data from another species of copepod demonstrated that their daily vertical migrations are not necessarily keyed to sunset and sunrise. Upward movement is in some cases completed in the late afternoon, several hours before sunset, as predicted by a new metabolic model proposed to account for the selective advantage of the migrations.

In a recently initiated project on behavioral responses to small changes in hydrostatic pressure, it has been learned that single individuals of the common sand-crab, *Emerita,* show a brief but strong and distinctive reaction to pressure changes of less than 1/100 atm. These animals offer a number of unusual advantages for further study of the little-understood, low-threshold, sensory system which underlies the behavior. More mathematically oriented research has led to a new sort of graphical treatment to describe the influences of the various factors involved in the regulation of population size under field conditions. This treatment demonstrates that "carrying capacity" of the environment for a species can be expected to depend directly upon average climatic conditions, such as temperature. That conclusion contradicts the widely held opinion that only density-dependent factors, such as food availability, predation, and disease, can determine equilibrium abundance of a species.

Dr. Theodore D. Foster again led the International Weddell Sea Oceanographic Expedition aboard USCGC *Glacier* in an investigation of Antarctic Bottom Water formation in the northwestern Weddell Sea. Dr. Jason H. Middleton collaborated in the physical oceanography program. Two current meters, which had been moored at the bottom of the Weddell Sea in 1975, were recovered. One of these meters provided a record of current speed and direction, temperature, and conductivity for nearly a year. This record showed that, while the flow of bottom water is quite irregular, the overall flow is a slow drift of about 1.3 cm/sec out of the Weddell Sea without a large variation in flow rate from summer to winter. A section of closely spaced Salinity-Temperature-Depth (STD) stations from the central Weddell Sea to the continental shelf just east of the tip of the Antarctic Peninsula showed that a layer of very cold, newly formed, bottom water may be traced continuously up the continental slope. These results seem to indicate that bottom water forms all year long in the Weddell Sea.

Dr. Theodore R. Folsom continued his studies of behavior of extremely small traces of artificial and natural radioactivity in the ocean using facilities developed for this purpose at the Mt. Soledad Laboratory for Marine Radioactivity Studies. Dr. Roger Grismore collaborated in continuing the investigations of minute amounts of gamma-emitting contaminants from global fallout in blood, liver, and other tissues of oceanic tuna. This year, comparisons of radioactive and total iron in these tissues were also added. Investigations of colloidal behaviors of plutonium and other alpha-emitting nuclides in seawater were continued by using new methods for determining diffusivities at the extremely low concentrations typical of the natural environment.

Dr. Carl H. Gibson's analysis of small-scale temperature fluctuations, obtained from an instrument package towed from R/V *Dmitri Mendeleev,* a USSR scientific vessel, reveals a complex system of layers below the wind-mixed surface water. In comparison with universal spectral forms and local isotropy, the layers are characterized as actively turbulent, fossil, and diffusively stratified. Instrumentation to measure small-scale conductivity, velocity and temperature fluctuations at towing speeds to 10 knots is undergoing development and sea trials.

Recent experiments strongly suggest that temperature sensors with exposed surfaces used over the ocean become sensitive to humidity fluctuations when coated with salt spray, so that low-level temperature signals may be contaminated. Apparently this effect accounts for many of the anomalous, sensible, heat-flux values, peculiar spectral results, and the so-called "cold spike" phenomena that have been observed over the ocean during the last few years since such measurements were first attempted. Now that the effect is known, a method for measuring over-ocean temperature fluctuations must be developed.

Dr. Joris M.T.M. Geiskes' laboratory continued investigations of the chemistry of interstitial water of marine sediments. Samples obtained from the Deep Sea Drilling Project, as well as samples obtained from box cores taken off Peru and on the Galápagos Rise, have been studied. Chemical studies of the solid phases of these sediments have been initiated.

Graduate students in Dr. Gieskes' laboratory worked on a variety of topics. Russell E. McDuff has developed methodologies for the estimation of diffusion coefficients in marine sediments, and has used the data obtained to model concentration-depth profiles of deep sea drilling interstitial water. These methods have been successfully applied to determine whether reactions in the sediments, in the underlying basalts, or in basal sediments are responsible for observed gradients in calcium and magnesium. Gerald S. Wirth continued his studies of the physical-chemical behavior of aqueous silica solutions. Alan M. Shiller, together with Dr. Gieskes, participated in Leg 1 of the Indopac Expedition, and studied the distribution of calcium alkalinity and total carbon dioxide along a longitudinal transect of the North Pacific Ocean (35 °N).

Dr. Walter F. Heiligenberg's research has been dedicated to the study of electrolocation in African electric fish and to comparing them with the unrelated South American


*Cheryl Terrass tests seawater samples for total alkalinity in titration apparatus on board R/V* Ellen B. Scripps *during one-day cruise off San Diego. Data from the experiments will be used in Dr. Joris M.T.M. Gieskes' marine chemistry investigations.*

*Heidi Hahn*

electric fish. In either group fish can be distinguished with regard to the mode of their electric organ discharge (EOD): pulse species fire their organ in short pulses and at rather irregular rates, which commonly rise in novel situations. Wave species fire their organ in a rather sinusoidal manner; for example, with a duty cycle of approximately 50 percent, and at highly stable frequencies. To reveal the adaptive significance of either mode of EODs, it was necessary to study the vulnerability of electrolocation to electric noise.

It has been found that only African wave species, *Gymnarchus,* and the South American wave species, *Eigenmannia,* are most vulnerable to sinusoidal signals with frequencies near the animal's own EOD frequency. Both species shift their EOD frequency away from the frequency of the interfering signal to protect their electrolocation ability.

The African pulse species, *Brienomyrus,* and the South American pulse species, *Hypopygus,* are most vulnerable to pulses coinciding with their own EOD pulses. Both species minimize the probability of coincidences by specific EOD maneuvers that serve to appropriately time the occurrences of the subject's EODs with respect to the EODs of a near conspecific.

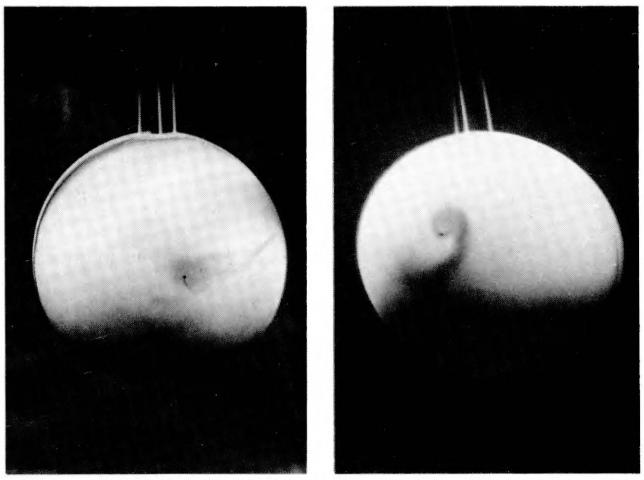
In a separate line of research, Dr. Heiligenberg studies spatial aspects of electrolocation by computer simulations of the fish's electric field associated with its EOD. This approach became necessary because no analytical solutions to this problem are available. The results obtained are in very close agreement with behavioral and electrophysiological data. Studies in this area have concentrated upon: (1) the range of electrolocation, (2) the nature of the electric image cast by the object upon the animal's body surface, (3) the significance of particular anatomical features, such as an elongated tail; for example, electric fish enhance electric images by bending their tail filament around objects of interest, and (4) the significance of body and skin resistivities.

As a side project, collaborative investigations with Drs. Dietrich L. Meyer and Theodore H. Bullock were conducted on the role of the electric sense in postural control. It has been found that the fish, *Eigenmannia,* electrically senses the angle of inclination of the substrate and tilts its body to maintain a perpendicular orientation to the substrate. This response conflicts with the gravitational response on non-horizontal substrates.

The Shore Processes Study Group, under Drs. Douglas L. Inman, Clinton D. Winant, and Robert T. Guza, is studying physical processes of the nearshore environment. Research objectives of the group include: (1) field and laboratory measurements of wind, waves, currents, and sediment transport, (2) identification and study of the important physical processes operative in the nearshore environment, (3) application of the understanding of these processes to environmental problems of the coastal zone, and (4) formulation of criteria for coastal zone planning.

The Shelf and Shore (SAS) simultaneous data-acquisition system consists of several shelf stations that are deployed offshore as sensor platforms, and a shore station for receiving and recording data. The shelf station is a buoyant spar anchored to the bottom using a universal joint. These stations can be instrumented with a variety of sensors for taking environmental measurements, which are telemetered to the shore station. The shore station can receive and record data from several shelf stations simultaneously. Data processing is done with a minicomputer, which has a direct communication link with the shore station to permit real-time data analysis.

A shelf station has been installed off Torrey Pines Beach (three km north of Scripps) for more than four years. This station has a line array of pressure sensors to measure wave energy incident to the coast. Dr. Inman and graduate student Steven S. Pawka are analyzing these data and compiling the results into a wave climate for the site. Other studies involving this installation are wave sheltering by offshore islands and edge-wave occurrence on the shelf.



*Two photographs show dye streaks produced by water motion induced by waves progressing from left to right past a submerged sphere in a study by Dr. Douglas L. Inman and graduate student Scott Jenkins, both of the Shore Processes Laboratory. Photo at left shows circulation proceeding over top of sphere. In photo at right, circulation carries dye from rear of sphere around the underside of the sphere.*

*Shore Processes Laboratory*

The mechanics of the equilibrium beach profile is being studied by Dr. Inman and graduate student David G. Aubrey. This study involved making weekly detailed measurements of beach profiles along three range lines. The beach profiles are then compared to the incident-wave energy, which is measured by the shelf station installation described above. The ultimate objective of this study is to attain a predictive capability for the beach profile configuration as a function of the incident wave energy.

Dr. Inman and graduate student Scott A. Jenkins have been using the Hydraulics Laboratory wave tank to study wave-induced forces on submerged spheres. Flow visualization, which is created by injecting dye from ports embedded in the model sphere, demonstrated the laminar nature of the flow near the sphere. Dye streaks produced by the laminar flow show steady streaming close to the surface of the sphere thus causing circulation around the vertical median plane. Such circulation generates a lift on the sphere and has bearing on understanding the motion of sedimentary particles in the oscillatory flow field created under waves.

Dr. Winant, using an array of thermistor chains and pressure sensors near Scripps Pier, is investigating breaking internal waves and bores in the nearshore environment. Breaking internal tides cause large temperature changes to occur rapidly in shallow water. Bottom temperature changes of 5 °C over a period of a few seconds have been measured at the end of Scripps Pier. These temperature changes are accompanied by currents on the order of 10 cm/sec that persist for several hours. A study of coastal currents on the shelf at the Naval Undersea Center oceanographic tower off Mission Beach, San Diego, has been completed and the results indicate: (1) currents are driven alongshore by surface tides and the longshore component of wind, and (2) onshore currents are primarily caused by internal tides. Studies of currents and thermal fluctuations on the shelf have been extended to the area near the San Onofre Nuclear Generating Station, San Clemente, California.

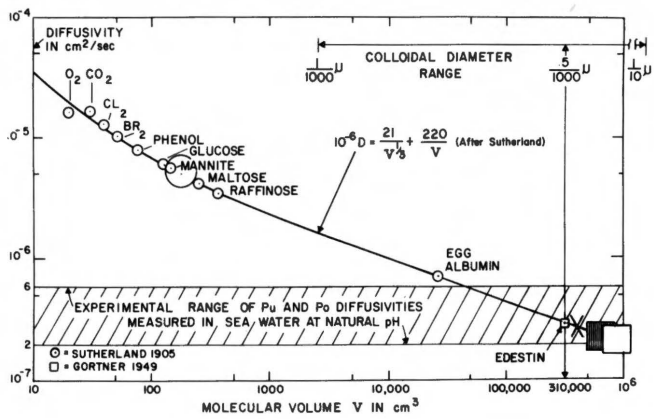
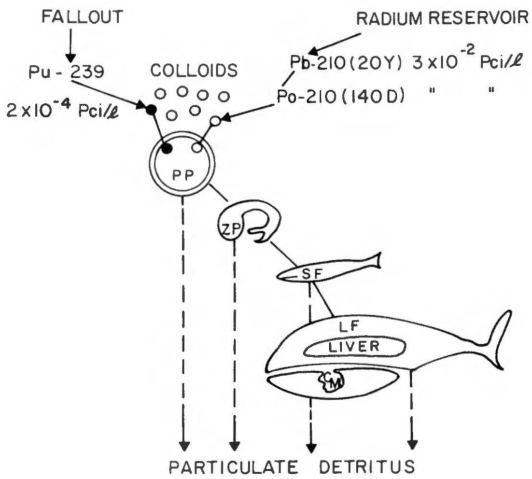



*Chart summarizes collodial particles suggested by 1975 diffusivity measurements at Mt. Soledad Laboratory for Marine Radioactivity Studies. Particles appear to carry natural polonium and bismuth, as well as contamination of artificial plutonium in seawater.*

*Mt. Soledad Laboratory for Marine Radioactivity Studies*




*Model suggests routes taken by natural polonium-210, a natural alpha radioactivity, in accumulating to extremely high levels in certain tissues (such as the caecal mass CM), of oceanic fish. The artificial element plutonium, also an alpha emitter, is rejected after being intensely accumulated by adsorption on solid surfaces (algal) of the first trophic level.*

*Mt. Soledad Laboratory for Marine Radioactivity Studies.*

Dr. Guza has been conducting laboratory and theoretical studies of waves on beaches. Special attention is being directed toward resonant, nonlinear wave interactions that result in an energy transfer from wind waves (incident from deep water) to oscillations trapped in the nearshore (edge waves). In particular, it has been found that groups of obliquely incident high-frequency waves can transfer energy to low-frequency, trapped oscillations. These long waves appear as a slow raising and lowering of the sea surface, and may be related to naturally occurring "surf beats" of periods 40-200 sec. A field experiment is planned to verify the relationship between high- and low-frequency waves.

Drs. Inman and Guza and graduate student Reinhard E. Flick have been conducting laboratory experiments aimed at understanding the distribution of energy in shoaling waves. Data from single-frequency, shoaling-wave experiments show that energy redistribution, from the primary frequency to the nonlinearly generated higher harmonics, is consistent with a simple nonlinear shoaling theory. Results also show that the wave height at the breakpoint and the breaker location can be accurately predicted from a consistent theory for spilling-type breakers. Shoaling experiments using two waves of slightly different frequency show that the energy redistribution that occurs is vastly different from that which occurs when each wave shoals separately. The differences suggest that there may be a mechanism for energy transfer into long period difference frequency waves in shallow water.

Dr. Inman and Charles E. Nordstrom have been involved with coastal-zone planning during this year. They prepared a report, "Man's Impact on the California Coastal Zone," for the California Department of Navigation and Ocean Development, which emphasized the importance of the physical processes operative in the coastal zone and applied this knowledge to five "problem sites" on the California coast. A second effort in coastal-zone planning was the initiation of a joint research project with the California Institute of Technology, Pasadena, to study sediment management in the southern California coastal area. Project scientists will try to determine the rate of sediment supply to the coastline, its transport along the coast, and losses from the coastal zone. Once this is determined, scientists will be able to (1) assess how long the sand beaches of this region will last with the reduced natural sediment input under present conditions, (2) formulate and implement measures to preserve threatened beaches, and (3) improve the sand management where man has artificially altered the near-shore sand-transport path.

Drs. Inman, William G. Van Dorn, and Scott S. McElmury and Rolland Harris, dredging consultant, have completed phase two of an investigation of sedimentation mechanisms in Navy port facilities and possible means of sediment management as economic alternatives to dredging. This work has included (1) field surveys of Navy port facilities to define their sedimentary environments in the light of possible control measures, and (2) continuing laboratory evaluation of control means, with emphasis on hydraulic jet arrays previously found to offer best promise in clay-silt environments.

While techniques for sand management have been under development at the Shore Processes Laboratory for some years, silt-management appears to require a different technology. Silt deposition in saline estuarine environments is a complicated electro-chemical process that is time- and pressure-dependent. Once newly deposited material becomes bonded to its substrate (24 hours), only dredging suffices to remove it. Present results suggest that maintaining suspension by low-level, jet-produced turbulence during slack water tide phases may prove to be a practical means of preventing deposition. To this end, a prototype 30-$m^2$ jet-array installation is proposed for the Navy port facility at Mare Island, California.

Dr. Charles D. Keeling and co-workers have continued their study of the atmospheric $CO_2$ buildup brought about by the combustion of fossil fuels: coal, petroleum, and natural gas. The study was begun in 1957 when stations were set up to measure continuously the abundance of $CO_2$ in air at Hawaii and Antarctica. Using the data collected over the past 18 years, Drs. Keeling and Robert B. Bacastow have devised a geochemical model that predicts atmospheric $CO_2$ levels over the next 1,500 years. Their most recent model includes $CaCO_3$ dissolution in marine sediments. It is

apparent that the extent of carbonate dissolution will be crucial in determining the rate of removal of $CO_2$ from the atmosphere over millennia, but not during the few hundred years when the readily available fossil fuel will probably be burned.

Efforts to model and predict future $CO_2$ levels have indicated a need for better knowledge of $CO_2$ equilibria between air and seawater. Toward this end, Peter R. Guenther has made a series of accurate measurements of $CO_2$ partial pressure in equilibrium with pure water. The second dissociation constant of carbonic acid can be more accurately calculated than heretofore possible. The measurements will continue with seawater of various salinities and at various temperatures.

Last year the World Meteorological Organization designated the Scripps Institution to be its Central $CO_2$ Laboratory. Highly accurate $CO_2$ reference gases are being supplied to laboratories in many nations, so that $CO_2$ measurements will be relative to the same set of standards.

J. Alexander Adams, Jr., has continued a global program of $CO_2$ measurement at the Canadian Weather Ship "P" at 50°N, at Fanning and Christmas islands near the equator, and at the South Pole. Air is collected, usually twice monthly, in flasks sent to Scripps for analysis. These data reveal regional variations in $CO_2$ production and natural variations in $CO_2$ uptake by the oceans.

In connection with this natural uptake, cross correlation of a barometric pressure index of the Southern Oscillation and small anomalies in atmospheric $CO_2$ abundance at Hawaii and the South Pole indicate an approximate 90 percent chance that atmospheric $CO_2$ is detectably influenced by year-to-year variations in the strength of the large-scale circulation of the winds. Dr. Bacastow has been investigating the mechanism that may produce this large-scale chemical interaction of the atmosphere and the world's oceans.

Dr. Robert A. Knox has continued his studies of equatorial ocean circulation. During the past year a program to monitor currents at 500-m depths at the equator north of the Seychelles has begun, and moorings have been successfully set, retrieved, and redeployed. The mooring system used is of lightweight, low-drag design and consequently can be deployed and retrieved by using locally chartered small vessels. This permits long-term maintenance of the moorings without the need for a major research vessel. It is planned to maintain these instruments for at least another year.

Michael J. McPhaden, a graduate student working with Dr. Knox, has completed the editing and analysis of the long series of current profiles collected by Dr. Knox near Gan, Maldives, from 1973-1975. McPhaden has now started some theoretical investigations of the effects of bottom topography, such as seamounts and ridges, upon equatorial flows.

Dr. R. Edward Lange has been analyzing data obtained with a free-falling, velocity/temperature microstructure device he and Dr. Charles S. Cox implemented the previous year. Results show that temperature microstructure in general has rates-of-strain less than $10^{-3}$ cm/sec/cm associated with them, implying that, as a general rule, microstructure is not associated with any discernible velocity field fluctuations of small scales.

Dr. Cox and graduate students Pavel Pistek and Daniel R. Cayan have studied the electrical conductivity of undersea rocks by detecting the transmission of natural atmospheric "static" through terrestrial rocks on land, and thence under the sea. The work was carried out onshore and offshore from Baja California in cooperation with the Mexican scientific institution Centro de Investigación Cientifica y Educación Superior de Ensenada, Mexico, and Juan Madrid of that institution.

The data collected consisted of simulated measurements of electric fields onshore and on the sea bed offshore at very low frequencies, *circa* one cycle per second.

An unexpected by-product of this research was the detection of signals induced by ocean surface waves at the floor of all deep-sea stations. The cause of these unexpected signals is electromagnetic induction from motions produced by nonlinear wave interference between oppositely moving wave trains. Such surface wave patterns are involved in the generation of microseisms.

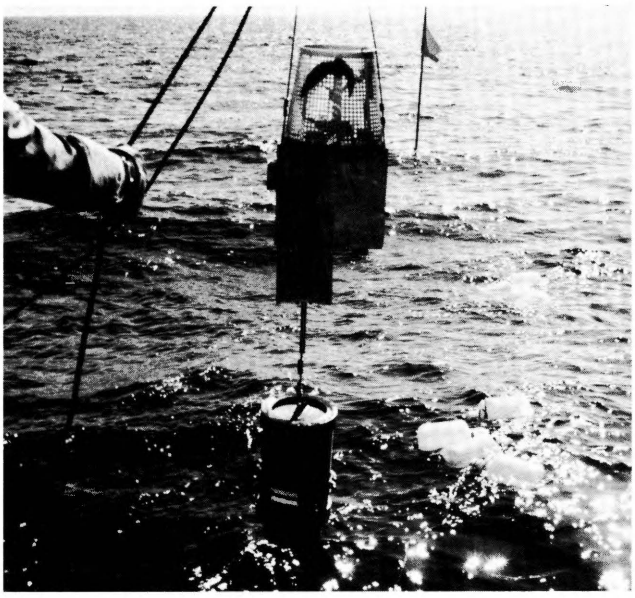
## *Physiological Research Laboratory*

Biochemical and physiological studies of cold-adapted fish were continued in Dr. Arthur L. DeVries's laboratory. To understand the rate of protein synthesis, *in vivo,* in cold-adapted fish, a high dose of radioactive amino acid was introduced into the liver via the portal vein of the antarctic fish *Dissostichus mawsoni,* which was kept alive in a running seawater aquarium in McMurdo Sound, Antarctica. The course of total plasma protein and glycoprotein antifreeze synthesis was followed kinetically by monitoring the appearance of radioactive proteins and glycoprotein with time. The special route of injection, the swamping effect on the amino-acid pool by a high dose of radioactive amino acid, and the kinetic analysis of protein synthesis eliminate all the pitfalls of conventional protein-synthesis studies. The results of these experiments give a reliable estimate of the rate of protein synthesis and indicate that the antifreeze glycoproteins were ribosomally synthesized in the liver rather than synthesized enzymatically.

Considerable progress has also been made in the mechanism of freezing point depressing activity of antifreeze compounds isolated from both antarctic and northern fish. In his PhD dissertation, Dr. James A. Raymond proposed an adsorption inhibition of ice-crystal growth mechanism by the action of antifreeze compounds. The abundance of polar or hydroxyl groups and the spatial arrangement of amino acids on antifreeze compounds enable them to bind to the lattice of a seed ice crystal and to force the ice to grow only along its unfavorable axis and thus lower the freezing point of an aqueous solution.

Dr. Harold T. Hammel has been collaborating with Dr. Eckart Simon and Dr. Christa Simon-Oppermann at the Max-Planck-Institut für Physiologische und Klinische Forschung, Bad Nauheim, West Germany, on an investigation of the neural receptors and neural network for osmoregulation. They have demonstrated that solutes in the blood, which increase the concentration of intracellular $K^+$ with respect to the concentration of extracellular $K^+$, increase secretion by the nasal salt gland of the peking duck. They also demonstrated that local cooling of the rostral brainstem inhibits secretion by the salt gland and water retention by the kidney. Randall E. Kaul, UC San Diego graduate student, is continuing the investigations on the peking duck and will also investigate osmoregulation in the Adélie penguin. Dr. Hammel has proposed that the origin of tachymetabolism in animals evolved only late in the Tertiary as the world climate approached the present ice age. This is contrary to the current view that the metabolic rate of mammals, which is five to ten times the rate per gram of tissue of reptiles, evolved concurrently with fur and with the high and constant body temperature. The fact that the mean surface temperature at mid-latitudes was 10° to 15°C warmer during the Mesozoic and well into the Tertiary suggests that tissues of mammals remained bradymetabolic as were their ancestral mammal-like reptiles. This fact suggests that mammals evolved insulation to reduce the influx of solar heat during the day and outflux of body heat at night and that they adapted to a high and less variable body temperature approaching 40°C. Only during the cooling trend in the late Tertiary is it likely that the heat of cellular processes was

*Dr. Gerald L. Kooyman (at left), and Dr. John B. West, UC San Diego School of Medicine, are impressed by Houdini, a sea lion, as he blows into his special cone to measure airflow and volume.*



*A deep-sea retrieval system used by Dr. A. Aristides Yayanos, of the Physiological Research Laboratory, catches amphipods in the deepest parts of the sea and returns them to the sea surface while they are under pressure (as great as 1,000 atms). Above photograph was taken from R/V* Alpha Helix *over the Aleutian Trench.*

*Maurice Buerge*
*Regent, University of the Pacific*
*Stockton, California*

accelerated to yield the tachymetabolism of modern mammals. James J. Rademacher, UC San Diego graduate student, is investigating several possible pathways by which cell functions were accelerated for heat production.

Drs. Per F. Scholander and Hammel continue their efforts to persuade the scientific community that solutes enhance the solvent tension in a solution and thereby account for all the colligative properties of the solution. They argue that the lower chemical potential of the solvent in a solution is attributed to this enhanced tension. If their arguments are acceptable, then the concept that solutes enhance the tension of the solvent will supersede the concept that solutes lower the activity of the solvent and alter its fugacity.

Investigations of respiratory adaptations in aquatic vertebrates continue to be the major thrust of Dr. Gerald L. Kooyman's research effort. Funding for this work comes from a National Institutes of Health project of considerable breadth on lung structure and function, which is headed by Dr. John B. West, UC San Diego School of Medicine. These studies deal with the structural nature of the lung and how it relates to gas exchange and ventilation. The Scripps portion of this research studies the behavior, physiology, and anatomy of those aquatic vertebrates that swim at high speeds and those that dive to great depths. These groups are being compared to less vigorous aquatic forms and to terrestrial animals.

Another major research effort is the study of the effects of oil contamination of the pelt on thermoregulation in fur seals. This work is in cooperation with the Seattle office of the National Marine Fisheries Service.

Pulmonary function tests are in progress with trained dolphins and sea lions. The sea lion investigations also include a study of energy requirements at different swimming rates. The sea lion work is a collaborative effort with Dr. Roger Carpenter, San Diego State University. The data-collection phases of this work are completed, and included the training of two sea lions to follow a cart around a ring-tank pool. While following the cart, the sea lions were required to exhale each breath into a tight-fitting cone. This made possible the collection of expired gas samples and the measurement of flow velocities of the expired gases. The Marine Mammal Commission, Washington, D.C., helped sponsor the ventilation studies. As part of that study several moribund animals were collected from local beaches. Efforts to restore them to health were unsuccessful, and a detailed analysis of the condition of their respiratory systems is in progress. Every animal beached had a serious lung ailment that very likely contributed to its death.

Graduate student Everett E. Sinnett will complete a study on the characteristics of pulmonary blood flow in the harbor seal during breathholding and diving. This is a joint effort with Dr. Eric A. Wahrenbrock and others of the UC San Diego School of Medicine. The degree of pulmonary shunting that occurs when the same harbor seals were dived to various depths was also assessed. In this way, the amount of lung collapse that occurs by compression during deep dives can be quantitatively determined. Closely related to the pulmonary shunt study of seals has been an analysis of gas exchanged in the yellow-bellied sea snake and the common water snake during deep dives. Much of this work was done at the Smithsonian Tropical Research Marine Laboratory in Panama. The snakes are ideal subjects for comparison with mammals because their lungs and pulmonary vasculature are much simpler.

A new type of recording system has been developed for monitoring behavior of marine mammals at sea. Several of these instruments will undergo extensive tests on St. George Island, Alaska, by utilizing northern fur seals as test animals.

Dr. Mark L. Laudenslager has been investigating the

choice a chukar partridge must make between living in an environment that is too hot and one that is too cold. The degrees of the heat and cold stresses are experimental variables, and they have been shown to influence the choice; for example, the percentages of time spent in the hot and in the cold environments. The effect on the bird's choice by altering brain temperature is under investigation.

Dr. Edvard A. Hemmingsen continued to study various gas-liquid interactions and the phase transitions producing cavitation in water and biological fluids under metastable conditions of high gas supersaturations. Essential, *in vivo* information is lacking as to where and how the bubbles form during certain conditions of decompression, and about the factors that decrease the cavitation stability of the liquids. The objective of these studies is to increase understanding of both the fundamental physical aspects of the cavitation process and the early etiology of gas embolism in organisms. This knowledge will also aid in elucidating the mechanism of gas secretion in the swimbladder of deep-sea fish.

Graduate student Wayne A. Gerth, collaborating with Dr. Hemmingsen in these investigations, is examining the cavitation behavior of interface systems, considered the probable sites of the bubbles *in vivo*.

In 1974 and 1975 amphipods were trapped and retrieved from the Aleutian and Philippine trenches. Most of the effort this year, by Dr. A. Aristides Yayanos and Ronald P. Van Boxtel, has been with microbial cultures, which were started by inoculating culture media with parts of amphipods. Most of the study sought high-pressure culture conditions for the microbes. Light and scanning electron microscopy have been used to characterize the cultures. Most of the microbes do not appear to grow at atmospheric pressure; this suggests that they require the high pressure of their deep-sea environment to function.

Drs. Yayanos, Andrew A. Benson, and Dr. Judd C. Nevenzel, UC Los Angeles, completed a study of some physical properties of a wax ester mixture isolated from a copepod. They found and quantitated the very large effect of temperature on the buoyant properties of this lipid. The compressibility of the lipid as a function of depth (temperature and pressure) has implications for understanding sound scattering by organisms such as copepods or myctophids, which contain large concentrations of this lipid type. Scientists found that the coefficient of compressibility changes abruptly at certain depth conditions and hypothesized that abrupt changes should be observed in the sound scattering by these organisms.

## *Visibility Laboratory*

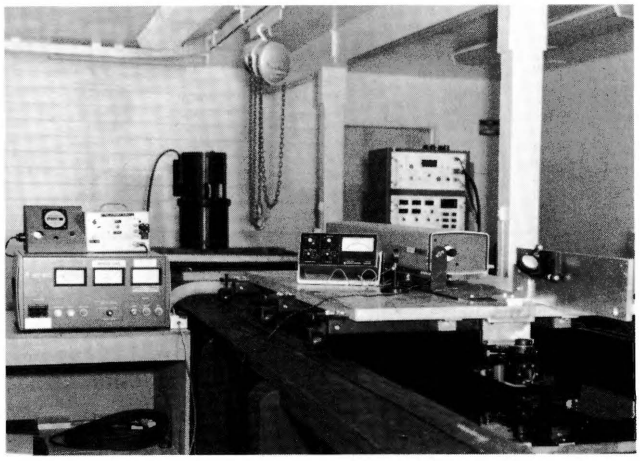
In the ocean environment light constitutes a vital input to the food-chain process. In both the atmosphere and the ocean, visible light is the basis for the observation associated with scientific investigations. These observations may involve cameras; photoelectric systems, such as television; or the human eye, aided by a host of optical devices, including microscopes, telescopes, holograms, and photometers. Because of the importance of these optical means of observation, the Visibility Laboratory conducts a broad spectrum of research related to the propagation of light, both natural and artificial, through water and through the atmosphere, and to the recording of image information by photographic cameras, photoelectric systems, and the human eye. Laboratory scientists also study the fundamentals of extraction and interpretation of the received image information.

### *Optical Oceanography*

Drs. Seibert Q. Duntley, Raymond C. Smith, Wayne H. Wilson, and Donald E. Silva continued experimental studies of the propagation of light in water. The very narrow angle forward scattering properties of water have important bearing on image formation. Increased knowledge of the processes involved is being sought through indoor tank experiments that used seawater transported by tank truck and tap water to which ingredients have been added to produce desired scattering and absorbing properties. The tank studies have been augmented by computer simulations performed by James L. Harris, Sr. These simulations have included the assumption of distributions of scattering particles each of which is defined in terms of size, shape, and index of refraction and the propagation of electromagnetic waves through the ensemble of particles by techniques of Fourier transformation to predict the emerging light field.

Roswell W. Austin, with assistance from Drs. Dale A. Kiefer and Smith, participated in a remote-sensing experiment conducted off the southern California coast. Using R/V *Dolphin* and a chartered vessel, they measured water properties constituting surface truth simultaneous with overflights of aircraft making spectroradiometric measurements. The objective was the collection of a complete set of data to relate the chlorophyll concentrations in surface waters to the spectroradiometric signal available in space. This experiment was a portion of a program of study directed toward evaluating the potential for determination of chlorophyll content from satellite observation, as for example, from the Coastal Zone Color Scanner, which is planned for the National Aeronautics and Space Administration NIMBUS-G satellite to be launched in 1978.

John E. Tyler and Dr. Smith continued to explore the quantum efficiency of photosynthesis. They have compiled and analyzed existing radiometric date pertinent to this problem and have outlined the specific needs for additional data. Drs. Kiefer and Wilson have been studying the relationship between phytoplankton growth rate and water



*The Visibility Laboratory's indoor facility for studying the propagation of light in water consists of a tank 13 m long, 1 m wide, and 70 cm deep, and includes a recirculating system and filter. Track-mounted tables allow instruments to be positioned where desired. A laser is shown with periscope optics for insertion of the beam into the water path. The large black object in the rear is one of the instruments used for measuring the volume-scattering function of water.*

*John C. Brown*

color, including the design of an experiment in which growth rate will be controlled and spectroradiometric measurements performed. Dr. Kiefer has also been involved in the study of thermodynamic models related to the regulation of phytoplankton growth.

### *Atmospheric Studies*

Fundamental measurements of the optical properties of the atmosphere, as they affect natural lighting and visibility, were continued from an Air Force C-130 aircraft assigned to the laboratory for this purpose.

The aircraft and instruments form a sophisticated airborne platform in which a variety of optical and meteorological measurements can be continuously made and recorded by means of a multichannel, magnetic-tape, data-logging system. This permits the aircraft to descend through a stratified atmosphere and gather detailed data of the vertical profile of atmospheric properties. The aircraft is usually operated in conjunction with a similarly instrumented ground station, so that corresponding zero-altitude data can be added to the vertical profile.

A principal activity for the year was a 62-day European field trip, in which the C-130 with a four-man technical team collected atmospheric data in West Germany, England, Netherlands, and Denmark.

### *Research Utilizing Image-Processing Facilities*

The computer image-processing research facilities at the laboratory consist of an IBM 360/44 computer, a variety of scanning and display equipment, a unique and versatile computer-program package, and special controls that allow the investigator to interact with the computer. This facility serves several different research activities. The computer capability was expanded during the year with the acquisition of additional core memory and disk storage.

Benjamin L. McGlamery continued his efforts in the development of a computer-simulation system for synthesizing in-water imagery. The system produces photographs that appear as if they were taken in water. The user is able to specify a light source with its angular distribution, a camera type and its location, and the scattering, absorption, and stratification properties of the water. The computer-simulation system mathematically determines how each of these factors alters the image and produces accurate computer-generated pictures showing how any type of underwater scene will appear when photographed by the assumed light-and-camera system. The new simulation capability is an important tool for evaluating existing in-water and light-and-camera combinations, as well as for optimizing the design of new systems. Any proposed in-water camera and lighting system can be given accurate performance trials before it is built, and the suitability of any existing equipment can be ascertained before its deployment.

McGlamery has also continued his computer simulations of new techniques for achieving improved resolution for telescope viewing. Earth-based telescopes are presently limited by the nonhomogeneous optical properties of the atmosphere. Within the last several years new techniques for improving telescope resolution have evolved and attracted national interest. The techniques involve the physical deformation of a secondary mirror in real time to compensate for the atmospheric turbulence. The procedures involved are quite complex and difficult to analyze, but the computer simulation is able to provide a means of evaluating the potential performance of postulated methods.

## *Institute of Geophysics and Planetary Physics*

The Institute of Geophysics and Planetary Physics (IGPP) is a University of California systemwide institute with branches at Scripps Institution and the campuses at Los Angeles, Riverside, and Davis. The institute at La Jolla is intimately related to Scripps Institution through their geographical proximity, and more importantly, through their common scientific interests.

Dr. James N. Brune continued his cooperative seismic research project in Mexico, worked on data from ocean-bottom seismographs, used physical models to understand earthquake-strong motion, and analyzed new data pertaining to earthquake source mechanism. A new project was begun in cooperation with the Institute of Engineering of the University of Mexico, Mexico City, to deploy an array of strong motion seismographs in northwestern Mexico. Data analysis was nearly completed, with Drs. William A. Prothero and Ian D. Reid, on data collected from the first ocean-bottom seismograph array. With Drs. Michael S. Reichle and George F. Sharman, studies have been completed on seismicity in the Gulf of California using sonobuoy hydrophones. With Alejandro Nava, graduate student, a new study of the structure of the Baja California Peninsula was begun using data from the July 1975 Piño Solo earthquake. With Dr. Brian E. Tucker and Jerry L. King, graduate student, digital seismic recorders are being used in the Garm Region, USSR, to study earthquake source spectra in cooperation with Russian investigators. With Dr. Gerald A. Frazier and Ralph J. Archuleta, Stephen H. Hartzell, and Steven M. Day, graduate students, studies were continued on the source mechanism of earthquakes, especially as related to earthquake hazard.

Dr. Thomas H. Jordan's research focused on seismic investigations of earth structure, with emphasis on lateral variations. His work on lower mantle heterogeneity indicates that descending lithospheric slabs penetrate the lower mantle to depths exceeding 1,000 km. With Stuart A. Sipkin, graduate student, he has completed a study of upper-mantle heterogeneity using multiply reflected seismic wave (ScS) data that provides additional evidence for the existence of deep continental roots. He has also been involved in several studies of present-day plate motions, attempting to use plate tectonic boundary conditions to place constraints on the complex tectonics of continental regions.

Dr. Kenneth C. Macdonald worked on near-bottom magnetic anomalies and their application to detailed tectonic studies of the Mid-Atlantic Ridge; inversion of magnetic anomalies and comparison with deep-sea drilling results; tectonics and seismicity of the Cayman Trough in the Caribbean; and, with Dr. Prothero, ocean-bottom seismometer measurements of earthquake activity of the Gorda Rise spreading center off northern California.

Dr. Hugh Bradner continued his work with offshore earthquake studies via sonobuoys; established a long-period seismic station on Fanning Island, in the central Pacific, to study teleseismic arrivals at this remote area (propagation from Central America along the "equatorial chalk line" is of particular interest); and has joined with others in preliminary work on a deep-sea neutrino-detection experiment (DUMAND). Dr. Reichle completed his PhD with the thesis "A Seismological Study of the Gulf of California: Sonobuoy and Teleseismic Observations, and Tectonic Implications." Mark R. Legg, graduate student, has made sonobuoy observations of seismicity at plate boundaries in the Caribbean and the equatorial Pacific.

Sir Edward C. Bullard has continued work on the opening of the Atlantic and has made calculations that suggest an explanation for the difficulty that has been experienced in

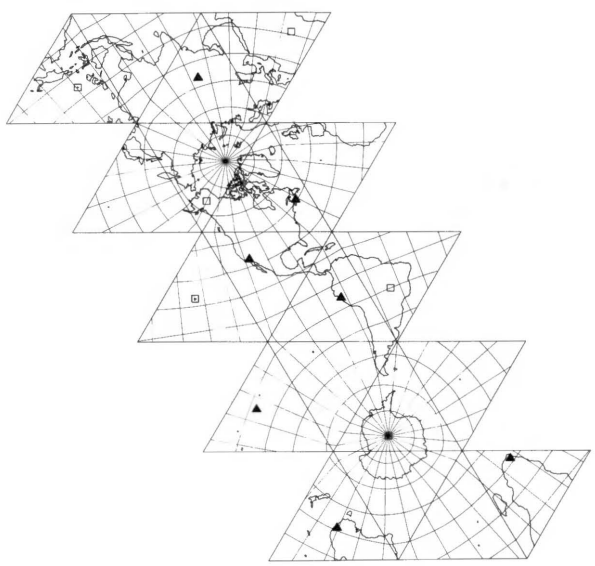
finding a detailed mechanism for a dynamo in the earth's core.

Dr. J. Freeman Gilbert has continued his research in long-period seismology. He has worked with Dr. Raymond P. Buland to develop procedures for obtaining the seismic source mechanism from a sparse network. A study of the dissipation of the earth's free oscillations is being performed jointly with Drs. Jordan and Buland. Dr. Buland worked on retrieving the seismic moment tensor of large earthquakes from a few high-quality seismograms. It now appears to be possible to routinely determine the source mechanism of all events larger than magnitude 6.5 on the Richter scale (and not rupturing the surface) with data from about ten instruments.

Dr. Jonathan Berger continued the direction of Piñon Flat Geophysical Observatory, near Palm Springs, studying the seismotectonics of southern California. In cooperation with Dr. Gilbert and Dr. William E. Farrell, UC Berkeley, stations of the Project IDA (International Deployment of Accelerometers) very long-period seismic network have been established in Ñaña, Peru; Canberra, Australia; Sutherland, Republic of South Africa; and Halifax, Nova Scotia.

Dr. Robert L. Parker, in collaboration with Dr. Steven P. Huestis, has developed analysis methods for magnetic fields based on linear and quadratic programing; these methods have been applied to near-bottom marine data yielding new, much more reliable values of the thickness of the magnetic layer. He has also begun work on the mechanism of isostasy using an approach devised by Dr. LeRoy M. Dorman; it is hoped that a large volume of gravity data from Australia will prove suitable for this study.

Dr. Roger J. Banks, visiting scientist from University of Cambridge, England, has been working with Dr. Parker on the application of inverse theory and linear programing techniques to investigations of the mechanism of isostatic compensation, with particular reference to the East African rift system. Work has also been started to improve estimates



*Drawing illustrates network for worldwide Project IDA, International Deployment of Accelerometers, a study of very long-period seismology by Drs. J. Freeman Gilbert and Jonathan Berger, of IGPP. Dark triangles indicate existing seismic stations; open squares locate proposed stations.*

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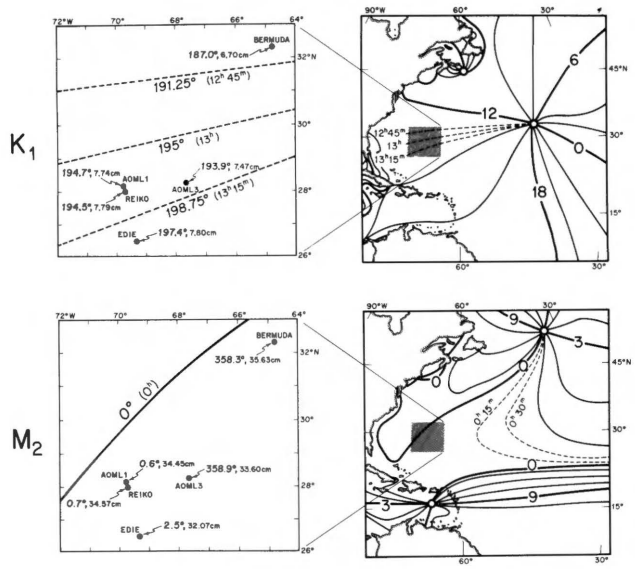


*Tide results shown in right panels are from ocean-bottom pressure observations made by scientists of the La Jolla Laboratories of the University of California's Institute of Geophysics and Planetary Physics (IGPP). Right panels show the late Dr. Günter Dietrich's cotidal lines in North Atlantic for $K_1$ and $M_2$, the principal daily and semi-daily tides, respectively. Values are in solar hours, with dashed curves designating IGPP's interpretation. The MODE (Mid-Ocean Dynamics Experiment) area falls within shaded square shown on enlarged scale in left panels, for comparison with results at MODE stations indicated by black dots.*

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of the long-period electromagnetic response of the earth, so that stronger constraints can be placed on deep conductivity structure using the theory developed by Dr. Parker.

Dr. Ralph A. Lovberg's small-angle infrared plasma scattering experiment passed through final phases of construction and testing of apparatus and is now ready for its intended final application; for example, diagnostics of the plasma in a large-scale thermonuclear fusion experiment (to be conducted in collaboration with UC Los Angeles in the "Tokamak" fusion experiment).

In physical oceanography, Drs. Walter H. Munk, Frank E. Snodgrass, Gordon O. Williams, and James L. Cairns (of the U.S. Naval Undersea Center, San Diego) and Bernard D. Zetler and Peter F. Worcester, graduate student, continued microstructure, internal wave, and acoustic transmission studies. Salinity and velocity sensors were added to the yo-yoing, mid-water capsule, and an in-capsule microprocessor makes possible the calculation of mean square microstructure gradients as well as programing the capsule to follow a $\sigma_t$ surface rather than an isotherm. A summer experiment in Lake Tahoe, California, studied microstructure at the time of maximum stratification and provided additional data on capsule descent dynamics. Reciprocal ship-to-ship acoustic transmissions over a distance of 25 km at a depth of 1 km showed first arrivals from a lower single path followed by upper-ray micromultipaths caused by fine structure (internal waves and intrusions). Multipath statistics for acoustic transmissions over much larger distances in an Atlantic experiment indicate energy at high frequencies is related to phase jumps (intensity fades) and at low frequencies to random walks.

Computations continue on large-scale subtidal fluctuations,

cross-correlating subsurface pressures ("detided" sea level plus atmospheric pressure) at Bermuda, Azores, and Iceland. Visiting Cecil H. and Ida M. Green scholar, Dr. George W. Platzman, continued his normal mode studies for various oceans. Dr. C. Henry McComas is examining third-order spectra as an indicator of nonlinear interactions and the resultant transfer of energy within the oceanic internal wave field. Dr. Blyth Hughes, visiting scientist from the Defense Research Establishment Pacific, Victoria, British Columbia, investigated the complementary theoretical problems of (1) underwater ambient noise production by second-order nonlinear interactions of surface waves, and (2) the parametric subharmonic generation of surface ripples by (high-intensity, high-frequency) sound; both treatments show regions of good agreement with experimental results.

Dr. John W. Miles continued with work on nonlinear waves. He developed a variational integral for surface waves that is equivalent to Hamilton's action integral and yields canonical equations for the Fourier amplitudes of the free-surface displacement and potential; a universal solution for the viscous damping of solitary (cnoidal) waves; solutions for oblique interactions among solitary waves; and solutions for both regular and Mach reflection of a solitary wave. This last work is of special interest for tsunamis and breakwater design.

Dr. Richard A. Krajcik's research included internal waves, the Fermi-Pasti-Ulam problem, and common nonlinear equations, with special emphasis on the Korteweg-de Vries (KdV) equation and solitary waves (solitons). Recent work has been on the relation of these nonlinear equations to Lie algebras which contain the "pseudopotential" information. Pseudopotentials are directly related to solitary waves (solitons) and Bäcklund transformations.

Working together, Drs. Myrl C. Hendershott and Richard L. Salmon and Greg Holloway, graduate student, studied theoretically the incorporation of wave processes, bottom relief, and stratification into closure theories of geophysical turbulence. The resulting second moment equations span the range of nonlinearity from weakly interacting waves to fully developed turbulence. They successfully rationalize the results of numerical simulations both at Scripps and elsewhere of quasigeostrophic flow.

Dr. George E. Backus extended his work on the phenomenological representation of seismic sources to include discontinuous displacement fields and to obtain a new method of resolving the fault-plane ambiguity. He also extended his work on the thermodynamics of the core to heat engines whose real efficiency is less than 1, and found that their apparent efficiency when their frictional heat is dumped in the hot source can be greater than 1 only if the real efficiency is greater than ½. Finally he showed that in a prestressed anisotropic medium the definition of the elastic tensor does not specify it uniquely; any member of a certain two-dimensional space of fourth-order tensors is eligible.

Dr. Frazier has been engaged in the development of finite element techniques for numerically simulating earthquakes in order to learn more about earthquake processes and potentially hazardous ground motions. Through the combined efforts of Dr. Frazier, Archuleta, and Day, 3-D finite element models have proven credible for reproducing analytical and laboratory results for earthquake-like slip along a dynamically spreading shear fracture. The numerical studies have provided new insights on the focusing of seismic energy in the direction of rupture propagation, the amplification of ground motion over confined sedimentary basins, and the modification of ground motion caused by the presence of civil structures.

Dr. Richard A. Haubrich learned that a significant coherence between polar motion and atmospheric pressure observations near the Chandler frequency indicates that the meteorological variation accounts for at least half of the Chandler wobble variance. The effectiveness of different spectrum analysis methods has been investigated to determine the bias and variance of estimated parameters of sinusoids plus noise. Both the Fourier method and nonlinear least squares were found superior to maximum entropy estimates of frequency and amplitude.

Dr. Robert H. Stewart used decameter radio waves in an experiment at Galveston Island, Texas, to measure the directional distribution and rate of growth of fetch-limited, seven-second ocean waves. In addition, he continued to help National Aeronautics and Space Administration (NASA) with the design of a new oceanographic satellite, SEASAT-A, and served as Scripps representative to NASA's Ocean Dynamics Advisory Subcommittee.

The work of Dr. Ken Watson, visiting scientist from UC Berkeley, included the following topics: (1) a study of ULF (ultra-low frequency) radio waves on the ocean bottom in collaboration with Dr. Charles S. Cox (the phenomenon studied is caused by the surface wave excitation mechanism and is related to the generation of microseisms); (2) a modal analysis of some internal wave data taken by Dr. Robert Pinkel from FLIP.

## *Institute of Marine Resources*

The Institute of Marine Resources (IMR) is charged with research, education, and public service in the broad area of marine resources utilization. IMR provides a basis for studies to improve the nation's supply of organic and mineral materials, to harness energy from the sea, and to extend knowledge about other resource issues such as recreation, transportation, pollution, and waste disposal at sea. IMR also provides for research into the social, legal, economic, and political aspects of man's related marine activities.

IMR facilities on the Davis and San Diego campuses of the University of California are administered from Scripps under John D. Isaacs, director. Assisting the director on policy and research plans are an advisory council staffed by public members appointed by the president of the university, and an executive committee staffed by faculty members.

A brief account of the principal IMR activities at Scripps follows, including those of the Food Chain Research Group (FCRG) and of that part of the Sea Grant College Program that is undertaken at Scripps. A full description of research is published in the periodic reports of IMR, FCRG, and Sea Grant.

### *Marine Food Chain Research*

The Food Chain Research Group (FCRG) conducts research on the ecology, physiology, and biochemistry of the organisms comprising the lower levels of marine planktonic food webs in relation to their physical and chemical environments. The recognition of key processes affecting plankton populations, in particular energy transfer between trophic levels, is of principal importance, since the complexities of marine food webs make simultaneous study of all components impossible. A major concern of the FCRG is the improvement of old and the development of new techniques of study and advanced instrumentation.

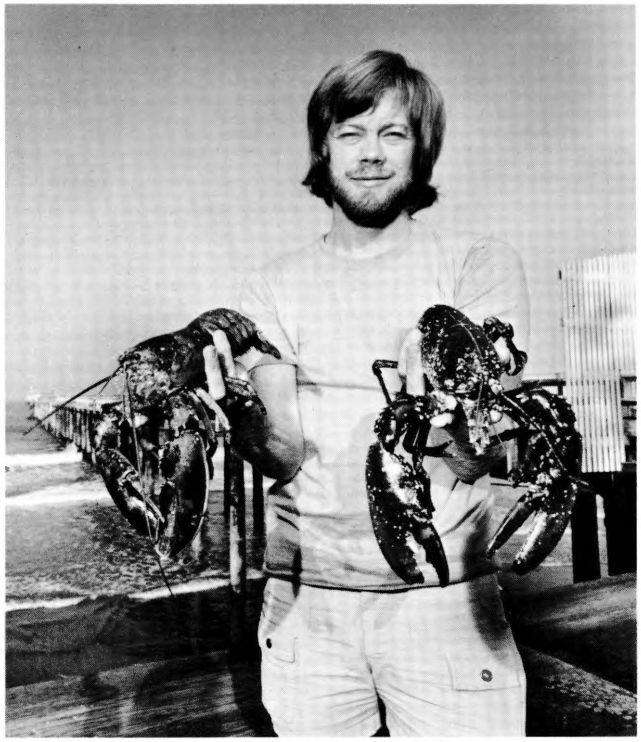
The major FCRG field program, initiated in September 1974, is a continuing series of cruises in the Southern California Bight to examine standing stocks and production of plankton by season with respect to water circulation and seawater nutrient chemistry. This is done with a view toward developing means of assessing the effects of man's activities

on the coastal pelagic ecosystem, such as the use of seawater for cooling purposes in power-generating stations.

Several FCRG investigators are part of an international team participating in the Controlled Ecosystem Pollution Experiment (CEPEX) being carried out in Saanich Inlet, British Columbia. CEPEX has the broad objective of assessing the impact on the total pelagic food web of long-term, low-level introductions of various pollutants; for example, heavy metals or hydrocarbons, into the marine environment.

Dr. Farooq Azam, in studies of microbial heterotrophic processes, finds evidence that free bacteria are responsible for the major portion of heterotrophy in the sea. Dr. Azam's CEPEX studies of bacterial populations, which have been subjected to heavy-metal pollution ($Cu^{2+}$ and $Hg^{2+}$ at 10 and 1 ppb, respectively), have shown rapid selection for resistant forms after initial inhibition of heterotrophic assimilation and respiration.

Dr. John R. Beers has coordinated the FCRG's continuing efforts to apply holography (three-dimensional image recording using coherent laser illumination) to plankton study through the development of a cine-holocamera to record behavioral activities. Dr. Beers's CEPEX studies include the examination of dynamics of microzooplankton populations in food webs subjected to pollutant stress.



*San Diego State University biologist Jon Van Olst, director of a Sea Grant lobster aquaculture project (located at Scripps), holds an adult Atlantic Ocean European lobster* (Homarus gammarus), *at right, and an American lobster* (Homarus americanus), *at left. These are being used for one of the first well-documented studies of hybridization of the two species. Interbreeding, a common animal husbandry practice, was undertaken in an effort to yield higher growth rates and increase disease resistance. The European/American hybrids are larger during the larval stage and appear to be slightly more resistant to disease, but studies have not yet been completed. The color and shape of all the offspring are a blend of the parents' characteristics.*

Dr. Angelo F. Carlucci is studying the growth characteristics of bacteria at low-nutrient concentrations, typical of much of the marine environment, and the use of these "low-nutrient" bacteria for assaying seawater for organic matter available to heterotrophs. His autoradiographic studies show that organic excretions of phytoplankton can be an important source of nutrients for bacteria under natural conditions.

Dr. Richard W. Eppley has been investigating causes for the inshore-offshore gradients of phytoplankton standing crops and productivity observed in the Southern California Bight. With Dr. William G. Harrison, Dr. Eppley examined phytoplankton nitrogen assimilation and determined nitrogen budgets both in the bight and for contained populations studied under the CEPEX program. Dr. Sallie W. Chisholm has found a daily rhythm in silicic acid uptake by diatoms in local waters; this implies a periodicity in their cell division.

Dr. Osmund Holm-Hansen continues studies utilizing adenosine triphosphate (ATP) as an index of biomass, thus increasing the sensitivity of the method of analysis. Studies of the energy charge of natural microbial populations have shown that the energetic state of cells may be used as a good indicator of their metabolic state. The quantum efficiency of natural phytoplankton was intensively studied by using a submersible scalar irradiance meter developed by Charles R. Booth.

Dr. Michael M. Mullin has been investigating the small-scale distributional relationships of phytoplankton and zooplankton. He finds that the high concentrations of phytoplankton and of the important copepod, *Calanus,* tend to co-occur. Calculation of the transfer of organic matter using data from small-scale sampling gives an altered conceptual view of plankton systems relative to the more traditional approach of averaging over large scales.

Dr. Peter M. Williams is probing the isolation and identification of copper-organic complexes in seawater, important because the speciation of copper affects its potential for stimulating or inhibiting phytoplankton and microbial growth. Examination of the compounds found in the major lipid fractions of important crustacea and fish has continued with a study of three members of an antarctic "food chain."

### *Sea Grant College Program at Scripps*

The University of California Sea Grant College Program, administered by the IMR, is headquartered at Scripps. Policy guidance for the program is vested in the IMR Advisory Council; administrative advice and program review rest in the IMR Executive Subcommittee for Sea Grant.

Sea Grant fulfills its mission of fostering the wise utilization of the resources of the sea and the defense against its hazards through its support of 35 projects and 60 trainees on California campuses. Sea Grant carries out its objectives through research, education, and training and public service. What follows here is a brief description of Scripps Sea Grant College projects. More detailed summaries are included elsewhere in this *SIO Annual Report.*

The "Ocean Education for the Public" program under Donald W. Wilkie and in collaboration with the Vaughan Aquarium-Museum staff and facilities, has involved 61,000 students in the group-education program on campus and in San Diego County schools and hospitals. The annual Symposium for Teachers on Marine Mammals was also held during the year.

"Physical Criteria for Coastal Planning," under Drs. Douglas L. Inman and Clinton D. Winant, is an ongoing project to provide reliable information to serve as the basis for rational coastal planning. Measurements were made using the Shelf and Shore (SAS) system, a versatile and accurate data acquisition system.

"Studies Toward the Optimal Management and Environmental Effects of Sea Urchin Fisheries," under Dr. Paul K. Dayton and Dr. Joseph H. Connell, UC Santa Barbara, is an investigation of the red sea urchin, *Strongylocentrotus franciscanus.* This research aims to determine the important population parameters necessary for managing a sustained-yield, sea-urchin fishery and to protect this important member of the nearshore benthic community from overexploitation. The investigation's results will continue to provide the necessary data upon which the California Department of Fish and Game, cooperating with this intercampus project, can establish rational management policies for a new commercial fishery.

"Seaweed Products: Applications in Algae Control, Mariculture, and Agriculture," a study under Dr. William H. Fenical, explored the application of certain toxic marine products in algae control, in aquaculture disease problem control, and as insecticides and herbicides. Two species of antibiotic algae, *Asparagopsis* and *Dasya,* were found to be active against the very lethal shrimp pathogen, *Vibrio;* and two compounds from *Laurencia* were shown to have selective insecticidal activity against the saltmarsh caterpillar and cabbage looper.

"Marine Natural Products Chemistry of Fouling Organisms," is a newly initiated program under Dr. D. John Faulkner, in coordination with Dr. Fenical's project. Dr. Faulkner's program seeks to apply the results obtained from basic studies of chemical ecology and antibiosis to the solution of problems such as selective control of fouling mechanisms and control of bacteria-caused diseases in mariculture.

"Wave Climate Modification and Monitoring," a study under John D. Isaacs, has advanced to the stage that an operational dynamic breakwater has been emplaced in San Diego Bay to protect fishing boats from ship-wake damage. Earlier pilot tests had found the breakwater to be very suitable for wave protection of harbor facilities and marinas, and the way now seems open for further testing under severe open-ocean conditions.

Two small projects that follow up and complete the original ecological study initiated under Dr. Edward W. Fager and Dr. Dayton are nearing completion. "The Potential Environmental Impact of the Japanese Alga, *Sargassum muticum,*" has been a study of the competitive interactions between this introduced Japanese alga and the native seaweed community of the southern California coast. The elucidation of the optimal clearing time was one of the major goals of the work. "Sand Bottom Community Structure and Artificial Reefs" has been a study of the sand community, particularly as it relates to the practical problem of the environmental effects of artificial reefs.

"Power from Salinity Gradients," under Isaacs and Dr. Gerald L. Wick, and Dr. Kurt Spiegler, of UC Berkeley, has been an intercampus venture designed to tap the large amount of potential energy existing at the interface between waters of differing salinity. Both "pressure-retarded osmosis" and "reverse electrodialysis" were investigated as were, more particularly, the influence of high salinity water on the membranes, the control of polarizing ions near the membrane surfaces, and membrane longevity.

## *Additional Activities and Services*

IMR has taken on a new and important public service. Waste-water discharges into the ocean and into San Francisco Bay are planned by several California cities. California's State Water Resources Control Board (SWRCB) is responsible for competent environmental analysis of this plan. In order to insure high scientific quality of the environmental studies, the SWRCB has engaged a panel of experts established by the director of IMR to review these studies and to assist with recommendations for monitoring programs. This engagement has already been very fruitful for the planned ocean outfalls of San Francisco and Eureka, California.

*Rep. Robert L. Leggett (D-Vallejo), chairman, U.S. House Subcommittee on Fisheries and Wildlife and the Environment (second from right), inspects mounted manganese nodule taken at 5,200-m depth on Pacific Ocean floor during a Scripps cruise and presented to him by Director Nierenberg during Congressman Leggett's visit to campus. Leggett and Assistant Director Jeffery D. Frautschy (at left) hold map showing area 2,400 km west of Tahiti from which nodule was dredged during Styx Expedition in 1968. John D. Isaacs, director of UC's Institute of Marine Resources (second from left), is an interested onlooker.*

Projects carried out by IMR with the support of the Foundation for Ocean Research in La Jolla include: (1) collecting thermophilic microorganisms from undersea hot springs at Punta Banda, Baja California, Mexico, and from inside condenser tubes of the power plant at Carlsbad, California, for studies of the growth and reproduction of these microorganisms; (2) detecting amorphous metalliferous deposits in bedrock crevices surrounding the vents of undersea hot springs as precipitate from hydrothermal solutions at Punta Banda; (3) investigating the characteristics of eggs and sperm as agents of energy transfer in the marine food web and as possible accumulators of some pollutants; (4) experimenting with and modeling sinking speeds of small particles in turbulent flow to elucidate the mechanism of particle suspension and support in fluids; (5) observing that relatively high pressure can cause high mortality of coliform bacteria. This technique may find application where other sterilization methods are undesirable; (6) determining whether the interaction between deep-water waves and surface currents can be used to measure current remotely and synoptically; and (7) describing the dynamics of sediment transport in tidal inlets, especially over rippled beds. Transport was found to relate to the 9th to 12th power of the fluid velocity. Thus small induced velocity perturbations can be very effective in mediating the shoaling of harbor inlets.

This year IMR contributed to the support of 33 graduate students, most of whom were engaged in research related to the mission of the institute. Three of these projects resulted in dissertations: on the dynamics of phosphate utilization by phytoplankton, on a revision of the Eastern Pacific Syngnathidae (pipefishes), and on the reproductive biology of two labrid fishes. Abstracts of these dissertations and of

the student research appear in the *IMR Biennial Report,* available from the institute on request. That report also lists the *IMR Reference Series, q.v.,* and the *IMR Technical Report Series.*

# SHORE FACILITIES AND COLLECTIONS

## *Facilities*

**Thomas Wayland Vaughan Aquarium-Museum** (5). The aquarium-museum is devoted to increasing the public understanding and appreciation of the ocean sciences through exhibits of living marine animals, museum exhibits, and a variety of educational programs. Important public information services are also provided through responses to written, telephone, and face-to-face inquiries.

The staff, assisted by approximately 50 volunteer docents, conducts a manifold educational program. This year through the major program, more than 61,000 students in educational groups toured the aquarium-museum. Other offerings include summer-school classes, Junior Oceanographers Corps, in-service training for teachers, and a career-experience program for high school and college students considering careers in marine biology, ichthyology, and other aquarium-related fields. Sea Grant College Program funds support a full-time coordinator for educational programs.

Aquarium-museum research involves marine animal maintenance systems, fish coloration, and fish disease. Through the aquarium's collecting facility, several thousand specimens are gathered each year for Scripps scientists. During 1975-76 additional facilities for chilling seawater were added to the aquarium system. There are now two cold-water tanks, 10°C, with a combined volume of 6,800 ℓ.

Although admission to the aquarium-museum is free, voluntary contributions from many of the more than 400,000 yearly visitors provide significant financial support. The aquarium-museum is open to the public daily.

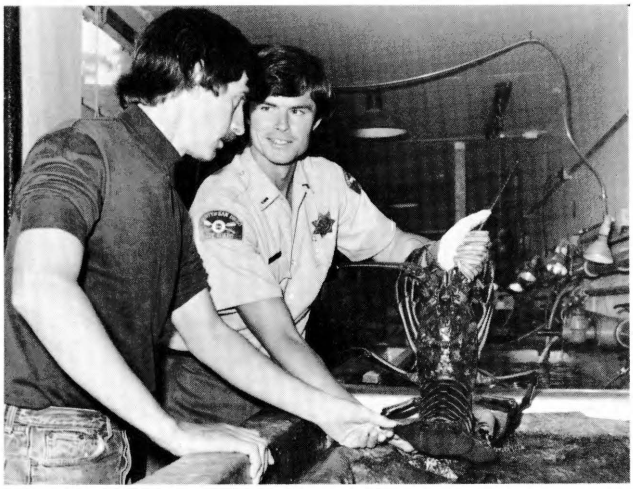
The aquarium-museum bookshop specializes in oceanographic literature, and selections vary from highly technical and scientific works to a variety of children's books and general-interest materials.

**Analytical Facility** (7) and (11). The facility provides the Scripps graduate student and staff with analytical instruments and professional assistance to aid in thesis or project research. Capabilities of the facility include an X-ray diffractometer for crystal lattice parameter and mineral identification; X-ray spectrometer for qualitative and quantitative analysis of elements above atomic number 12; atomic absorption spectrometer (A.A.) for quantitative determination of elements in solution; heated graphite atomizer (attachment to A.A.) for determination of elements in solids with detection limits of $1 \times 10^{-12}$ grams; amino-acid analyzer for amino-acid characterization; gas chromatograph for separation and identification of molecules in the gas phase; gas chromatograph/mass spectrometer for qualitative separation and analysis of organic compounds; a Nova 1210 minicomputer for data handling; carbon-dioxide analyzer for sample carbon and carbonate content in terms of carbon dioxide; and a Cambridge S4 scanning electron microscope for examination of samples at magnifications up to 100,000X enhanced by a depth of field far surpassing the light microscope. Two Siemens electron microscopes, together with freeze-etching

*Construction of new Scripps Library went from ground breaking to near-completion in 1975-76. During ground-breaking ceremonies, UC San Diego Chancellor William D. McElroy speaks beside library model at construction site on Scripps hillside. Wearing hardhats, other speakers were, from left, Melvin J. Voigt, university librarian; contractor S. F. Nielsen, of Nielsen Construction Company; and William J. Goff, Scripps librarian. In middle photo, manning shovels and pick at ceremonies are, from left, Director Nierenberg, Chancellor McElroy, and Nielsen. Bottom photo shows building nearing completion. The new facility is scheduled to open in January 1977.*


*Don Wilkie, Vaughan Aquarium-Museum director (at left), explains exhibit of rare coelacanth fish to Yoshiyuki Hatayama (center), a surgeon, and Masatatsu Orii, leader of Rotary International Foundation-sponsored visit to southern California by business and professional men from Nagoya area of Japan.*

*Photo by Lee Dodds, courtesy of* La Jolla Light.



*Large, rarely seen, California spiny lobster weighing nearly 5.5 kg was given to Vaughan Aquarium-Museum by Lt. Peter Zouvanyi (at right), San Diego County lifeguard who caught 75-cm specimen in 6 m of water off Solana Beach, north of La Jolla. Aquarium curator Charles J. Farwell (at left), estimated age of bull male at 22 years. A lobster of this size is seldom seen along southern California coast.*

and accessory equipment, provide high resolution in the study of ultra-fine structure. The facility offers complete sample-preparation laboratories, including "wet" chemistry and rock-processing laboratories, a table-top Olivetti computer, and geological field equipment.

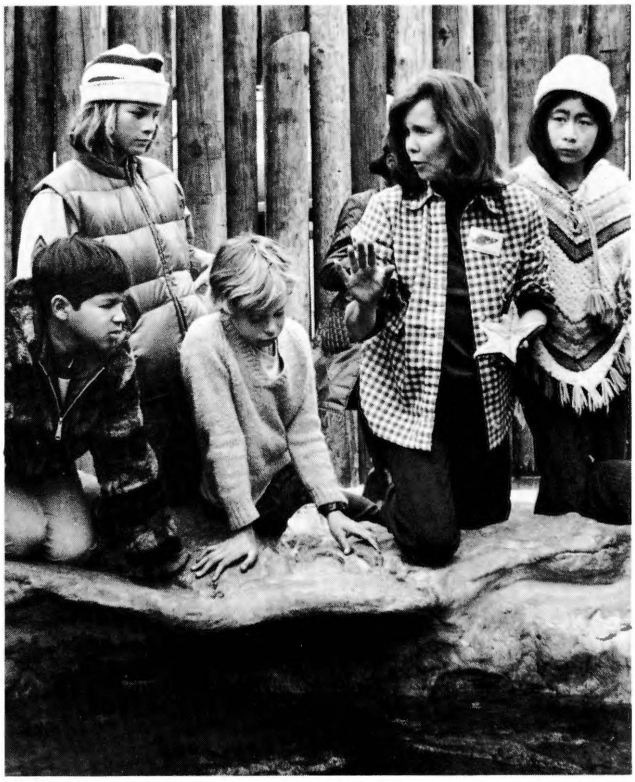
**Cardiovascular Research Facility** (13). Established in 1965 as a joint enterprise of Scripps Institution's Physiological Research Laboratory and Scripps Clinic and Research Foundation, La Jolla, this facility consists of an experimental animal colony, equipment for physiological research involving measurements of circulatory and cardiac functions in free-moving animals, and a Cardiovascular Instrumentation Development Laboratory in support of physiological research.

**Diving Facility** (16). The diving facility contains showers, dressing rooms, diving-equipment storage, air compressors, an air volume bank, diving cylinder storage, and an overhaul and repair facility. A boat is also available to the diving facility.

Scripps's scientific diver-training program, the oldest of its type in the country, trains more than 70 scientists and technicians annually. Through this training in the use of SCUBA as a scientific tool, they may obtain data available by no other means. These classes are generally limited to UC San Diego personnel with the need to work or study underwater; however, federal, state, and local government employees may be admitted by special permission. There are currently 130 faculty, staff, and students who make an average of 4,000 scientific and technical dives per year. These dives are completed in all the oceans of the world, including the Arctic. During the past ten years Scripps divers have amassed more than 60,000 accident-free scientific and training dives.

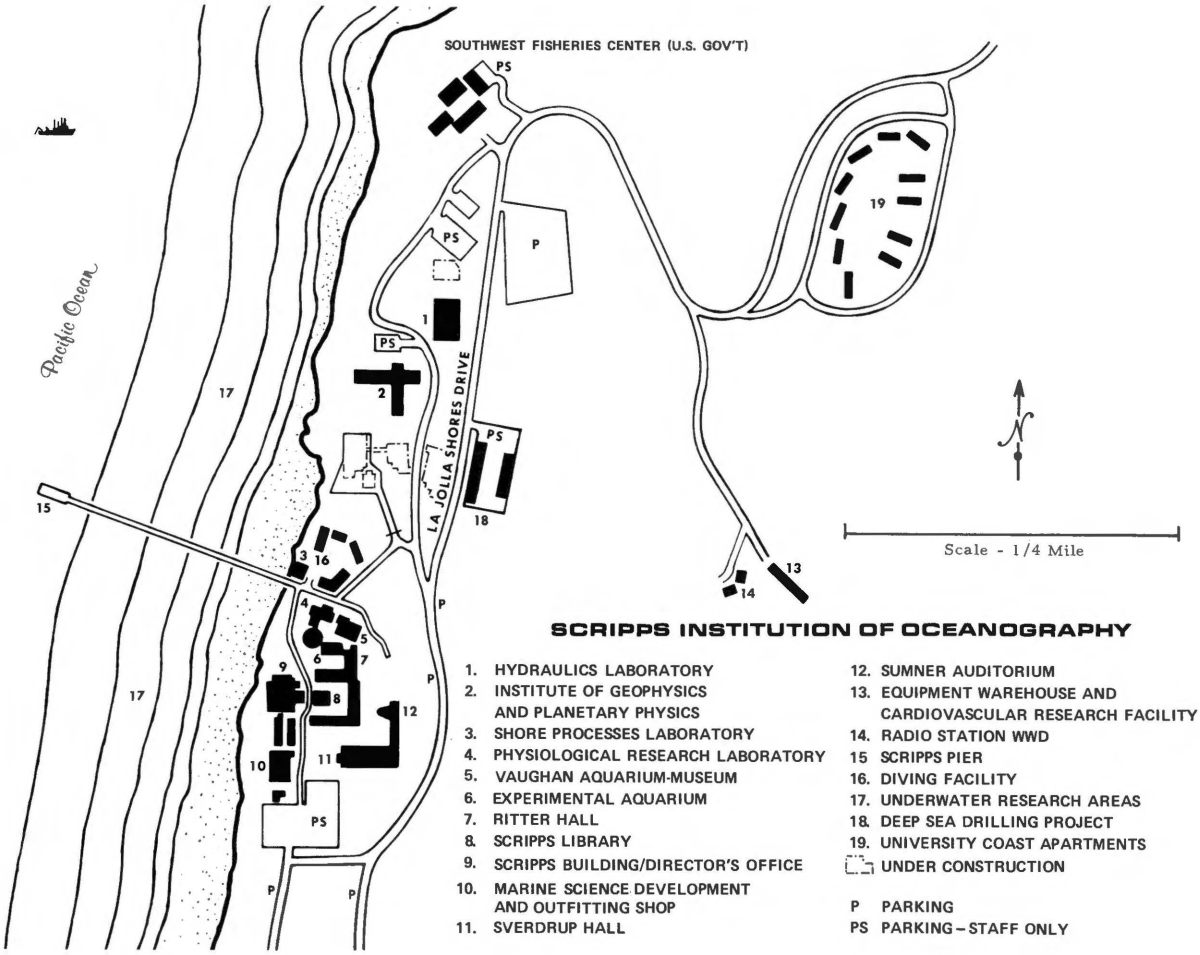
**Electron Microprobe Laboratory** (11). This laboratory handles the chemical analysis of volumes as small as one cubic micron at concentration levels above a few hundred parts per million. This is achieved by accurate spectrographic measurements of the X-radiation from the area analyzed, which is excited by a focused electron beam. The instrumentation is used primarily in studies of mineralogical, petrological, and solid-state physical problems.

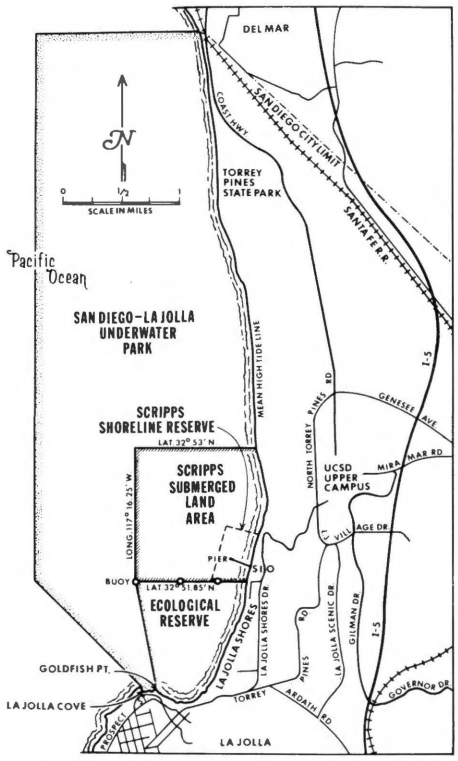
**Experimental Aquarium** (6). Used by faculty, research staff, and graduate students for various studies of living plants and animals, this aquarium is provided with ambient and chilled seawater, and is equipped with five rooms for controlled environmental studies, 20 tanks, and nine seawater tables.



*At aquarium-museum onshore tide pool, docent Petriea Maher explains the physiology of a starfish to some of the more than 61,000 students who participate in special aquarium-museum educational programs each year.*

*Jackie Janke*




*As Director Nierenberg looks on, Mary Carol Isaacs (at right), presents a statement to Librarian Catalina Lopez de Baumgartner pledging gift of book bindery equipment to Escuela Superiór de Ciencias Marinas (ESCM), Universidad Autonoma de Baja California, in Ensenada, Mexico. The gift from People-to-People was presented during annual visit to Scripps of 80 oceanography students and their instructors and wives from ESCM. This activity was coordinated by People-to-People, of which Mary Carol Isaacs is chairman, a women's international-relations interest group of UC San Diego Oceanids, composed of wives and women faculty members.*

**Hydraulics Laboratory** (1). This laboratory is equipped with a wind-wave channel 43×2.4×2.4 m in size with a simulated beach and a tow cart for instrument and model towing; a 15×18-m wave-and-tidal basin with an adjustable simulated beach; a 40-m, glass-walled, wave-and-current channel; a granular fluid mechanics test facility consisting of a 6×12×3-m concrete basin; a 10×1×1-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 used for various physical and biological studies. All wave generators in the laboratory incorporate servo systems and can be computer or magnetic-tape controlled. An IBM 1130 computer system is the central controller for data acquisition and data processing in conjunction with experimental use of the various facilities.

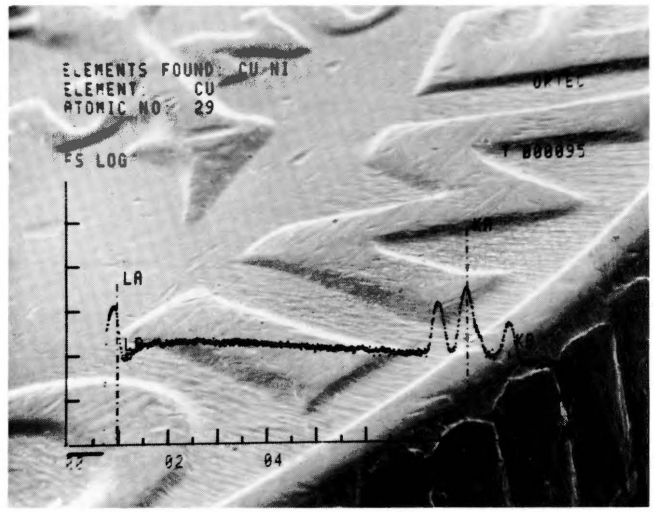
**Kendall Frost Mission Bay Marsh Reserve** (Mission Bay, San Diego). Approximately 20 acres of marshland in Mission Bay belonging to the university constitute a marsh preserve and wildlife refuge designated for teaching and research, as one unit of the University of California Natural Land and Water Reserve System. The City of San Diego has designated the surrounding tidal and shoal waters be retained in a natural condition.

**Marine Science Development and Outfitting Shop** (10). This shop is equipped with precision tools and has a staff of toolmakers and diemakers who design, develop, and fabricate research equipment and instrumentation in support of the various laboratories at Scripps, the Southwest Fisheries Center of the National Marine Fisheries Service, UC San Diego, the Scripps fleet, and other educational and governmental organizations throughout the United States. The shop carries an extensive stock of fabrication materials and provides forklift service with a 6,804-kg-capacity unit.

**Mass Spectrographic Equipment** (7) and (11). 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.

**Mt. Soledad Laboratory for Marine Radioactivity Studies** (3 km south of Scripps campus). This laboratory provides the highly specialized equipment and isolation (from other research areas where relatively large amounts of radioactivity are employed) needed for the study of the natural radioactive background in the ocean. It also provides for the detection and measurement of minute traces of artificial radioactivities that are entering the ocean and accumulating in many ocean organisms as a result of weapon tests and the industrial and research use of nuclear materials. These studies yield information needed for predicting the impact expected from increased use of nuclear fuels in the future. This facility is continually expanding its capabilities for analyzing numerous biological samples for plutonium and other alpha emitters. A high-precision, computer-controlled, flame spectrometer is employed to study nonradioactive traces of natural cesium and other alkaline metals in the ocean.

**Petrological Laboratory** (8). This facility provides thin-sectioning, microprobe sample preparation, and rock-surfacing services to staff and students of Scripps and associated research groups. All types of submarine and subaerial igneous, metamorphic, and sedimentary materials




*Scanning electron micrograph of a dime with overlay of elemental analysis read-out that is simultaneously displayed on an energy-dispersive X-ray analyzer attachment. The combination of these two units enables scientists to view and photograph a sample while observing its chemical composition, in this case, copper and nickel.*

*Ellen L. Flentye*

in various states of lithification are prepared here by plastic-vacuum techniques and other types of impregnations for microscopic study. The laboratory is administered through the Geological Research Division.

**Physiological Research Laboratory Pool Facility** (4). This facility consists of a holding pool for large marine mammals and fish; a ring pool of 10-m radius equipped with a variable-speed trolley carrying instruments for various hydrodynamic and biological studies of mammals and man; and a behavioral pool for echo-location 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. The ring pool was used in 1975-76 for energy consumption and respiration studies on swimming and diving sea lions.

**Radio Station WWD** (14). Licensed to the National Marine Fisheries Service and operated by personnel from Scripps's Marine Facilities Division, Station WWD provides communications services to both organizations as well as to other governmental and institutional ships and to the Deep Sea Drilling Project's D/V *Glomar Challenger;* and weather advisories to the fishing fleet and to scientific and operational traffic. The station has worldwide capabilities. Voice, CW, radio-teletype, and facsimile transmissions can be handled by the station, which operates 12 hours a day Monday through Friday, and eight hours a day on Saturday, Sunday, and holidays.

**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 8×15-m enclosed platform in 40 m of water, offering 1,372 m of unobstructed range.

**Scripps Library** (8). The library's outstanding collections in oceanography, marine biology, and undersea technology complement its impressive store of oceanographic information. In addition to monographs and serials in mathematics, physics, chemistry, geology, and zoology, the main collection includes extensive expedition literature. As of June 30, 1976,

the library housed 111,993 bound volumes; 26,278 maps and charts; 20,611 reprints; 27,222 documents, reports, and translations; and 3,806 pieces of microcopy. The Documents/Reports/Translations Collection is comprised of a nucleus of technical reports and memoranda published by Scripps and supplemented by reports and translations from other educational, governmental, and industrial institutions involved in marine research. The Map and Chart Collection includes atlases, nautical charts, and geological and topographic maps. The collection emphasizes nautical information, and is a depository for U.S. Geological Survey geologic maps and related publications. The library's Rare Book Collection has many old and valuable treatises and encyclopedias in science and natural history, and numerous accounts and journals of famous voyages of discovery.

**Scripps Pier** (15). A familiar landmark is the 305-m Scripps Pier, built in 1915 as a platform for serial observations, data gathering, and scientific work. Sea temperature and salinity observations have been made daily since August 1916, from instruments housed at the pier's seaward end. Here also an automatic gauge records tidal fluctuations.

**Seawater System** (15). Pumps located on Scripps Pier deliver seawater to the laboratories and aquaria of Scripps and the Southwest Fisheries Center. The seawater system utilizes two high-speed sandfilters and two concrete storage tanks having a total capacity of 439,060 $\ell$. Delivery capacity is 5,300 $\ell$ per minute.

**Shipboard Computer Group** (7). 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 ashore in Ritter Hall on campus.

The IBM 1800 computer systems are equipped with printers, card readers, typers, plotters, disk memories, and magnetic tape units for batch-processing and real-time data storage, processing, and display. They are interfaced to ship's course and speed and satellite navigation receivers for precise determination of data location. Scientific instruments interfaced to the computer for automatic data acquisition and storage include STD (Salinity/Temperature/Depth), XBT (Expendable Bathythermograph), magnetometer, transponder-ranging inputs for the Marine Physical Laboratory's Deep-Tow vehicle, and radio-relayed sonobuoy, seismic-refraction, and wide-angle reflection signals. Data are routinely stored on disk and magnetic tape for return to Scripps, and they may be processed, correlated by time or position, and displayed numerically or graphically, at sea and ashore.

A digital seismic-reflection system, under development and first tested in 1975-76 as a joint venture of the Shipboard Geophysical Group and SCG, is capable of sampling up to eight analog signals at 1 kHz sample rate (8 kHz total) and recording them on a high-density digital magnetic tape. The sampling and recording capability can be applied to any digital or analog time series, but will be used primarily with acoustic geophysical transducers.

**Shore Processes Laboratory** (3). This laboratory is the research facility utilized by the Shore Processes Study Group, whose principal interest is the investigation of the nearshore environment. This is a multipurpose building with a data processing laboratory, electronics laboratory, and general work area. The lower level houses a sedimentation laboratory, calibration laboratory, and mechanical shop. The data processing laboratory includes a shore receiving station for telemetered data, analog and digital magnetic tape recorders, and strip-chart recorders. Data processing is achieved with an Interdata Model 70 minicomputer equipped with a disk storage unit, digital tape recorders, a paper tape recorder, graphic plotter, and CRT terminal. The building also houses an extensive library of reference material on coastal-zone processes and a collection of nearshore sediment samples.

**Southwest Regional Calibration Center** (Off campus, in San Diego). This facility, a branch of the National Oceanographic Instrumentation Center, is operated by the Marine Physical Laboratory under contract with the National Oceanic and Atmospheric Administration. Work of SRCC, which is equipped to calibrate oceanographic instrumentation for governmental and non-governmental research, concentrates mainly on STD/CTD equipment, mechanical bathythermographs, and laboratory salinometers.

**Underwater Research Areas** (17; see also URA map). Considerable study takes place in the coastal waters adjoining the Scripps campus. These waters include special reserves, some of which have been set aside specifically for research.

**Scripps Shoreline Reserve** — The oldest extant reserve in the underwater research areas off the Scripps campus is the Scripps Shoreline Reserve (also identified as "The San Diego Marine Life Refuge" CFG 10902), which consists of a 100-acre tract of seashore and ocean including the area of the beach together with the waters of the ocean to a line 300 m seaward of the lowest low tide. It extends a north-south distance of 850 m between the southern end of the Scripps seawall and the northern property line of the National Marine Fisheries Service. All marine plants and invertebrates are protected for research purposes and may be collected only with permits issued by the University of California through the Vaughan Aquarium-Museum. This area has been used extensively for research by staff members and graduate students and, in addition, is used for instructional purposes by outside institutions as well as UC San Diego.

**Scripps Submerged Land Area** — The University of California leases from the City of San Diego approximately 2.6 $km^2$ of submerged land that extends seaward and to the north of Scripps. Included within this area is a Navy-designated, restricted area that is reserved for installation of oceanographic instruments by the Navy and Scripps. This area is currently unmarked.

**Ecological Reserve** — The 580-acre San Diego-La Jolla Ecological Reserve extends southward from the Submerged Land Area to Goldfish Point in La Jolla. The zone was established primarily for conservation, and is protected from

*Robert L. Ranf, Marine Science Development and Outfitting Shop toolmaker and diemaker, rotates turntable on horizontal milling machine as he prepares to cut a slot in Deep Sea Drilling Project core catcher.*

any collecting. A group of trained volunteers from Scripps's aquarium-museum often acts as guides. The reserve, established in 1972, has shown measurable return to its original pristine condition. The Ecological Reserve and the areas west and north of the leased Submerged Land Area are included in the 4,600-acre San Diego-La Jolla Underwater Park.

## *Special Collections*

**Deep Sea Drilling Project Core Repository** (18). Scripps houses the West Coast Repository for cores collected by DSDP. The DSDP is part of the National Science Foundation's (NSF) Ocean Sediment Coring Program. Cores stored at this repository come from the Pacific and Indian oceans. (Cores from the Atlantic, Mediterranean, Antarctic, and Caribbean regions are stored at the East Coast Repository at Lamont-Doherty Geological Observatory of Columbia University.) Samples from these cores are made available to qualified researchers throughout the world under policies established by NSF.

**Geologic Data Center** (5). Most of the geological/geophysical data collected by Scripps vessels while underway are processed and archived at this location. Navigation, depth, and magnetics 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 approximately one million nautical miles of Scripps cruises, as well as tracks of DSDP *Glomar Challenger.* The data center also maintains a multidisciplinary index of all samples and measurements made on major Scripps cruises.

**Geological Core Locker** (3-basement). This collection has more than 4,000 deep-sea sediment cores, which are kept under refrigeration. It also contains the bulk assemblages of rocks and manganese nodules collected mainly by dredging from the Pacific and Indian oceans. These materials are available for study by scientific investigators; students may have access to the cores.

**Marine Invertebrates** (Zooplankton Collection. 7, and 16 km southeast of Scripps). In this collection are nearly 64,000 documented zooplankton samples; of these more than 21,000 are from special collections and expeditions and some 1,250 from Isaacs-Kidd mid-water trawls. Included are sorted specimens and identified collections of major taxonomic groups, including the adult cephalopoda. Yearly additions to the collection average between 1,000 and 1,500 samples. Most samples are supplemented by meteorological, hydrographic, physical, and chemical data.

**Marine Vertebrates** (Fish Collection. 7). More than 2,500 cataloged species of marine fishes and in excess of one million specimens are in this collection. Added in fiscal 1976 were 568 collections of bathypelagic and shore fishes.

**Oceanographic Data Archives.** Tide-gauge records, taken daily since 1925 at the Scripps Pier, are held at the Scripps Diving Locker for two months and then mailed to Chief, Pacific Tide Party, National Ocean Survey, 1801 Fairview Avenue East, Seattle, Washington 98102.

Temperature and salinity records taken daily since 1916 from Scripps Pier, 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 Data Collection and Processing Group of the Marine Life Research Group. Summaries of the short-station data, issued annually, are available upon request to Data Collection and Processing Group, Scripps Institution of Oceanography, S-001, La Jolla, California 92093.

# PUBLICATIONS

## *Introduction*

The publications of the Scripps Institution are the end product of the faculty and staff's research. These publications are usually highly technical, ranging from long taxonomic descriptions to short data reports. Scripps publications are generally distributed by subscriptions, exchanges, or government contracts.

Below is a complete listing of the Scripps Institution of Oceanography publications for fiscal 1976. Detailed availability information is included for each series.

## *Bulletin*

In *Bulletin of the Scripps Institution of Oceanography* are published lengthy, in-depth scientific papers by the faculty and staff. The bulletin is the only SIO publication available by subscription. For information about subscriptions and a list of those numbers available please write: University of California Press, 2223 Fulton Street, Berkeley, California 94720.

Cited below are the three volumes published during 1975-1976:

V.21 PERRIN, William F. Variation of Spotted and Spinner Porpoise (Genus Stenella) in the Eastern Tropical Pacific and Hawaii. 206p.

V.22 RENZ, G. W. The Distribution and Ecology of Radiolaria in the Central Pacific: Plankton and Surface Sediments. 267p.

V.23 WORMUTH, John H. The Biogeography and Numerical Taxonomy of the Oegopsid Squid Family Ommastrephidae in the Pacific Ocean. 91 p.

## *CalCOFI Atlas Series*

The *California Cooperative Oceanic Fisheries Investigations* (CalCOFI) *Atlas Series* contains data on the hydrography and plankton of the region of the California Current. The series reflects the work of the CalCOFI program, sponsored by the State of California under the direction of the state's Marine Research Committee, of which Scripps is one of five cooperating agencies.

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. Those institutions or libraries interested in acquiring atlases please write to: Dr. Abraham Fleminger, Scripps Institution of Oceanography, A-001, La Jolla, California 92093.

Atlases issued this year are listed below.

*No. 22 NAMIAS, J. Northern hemisphere seasonal sea level pressure and anomaly charts, 1947-1974. 1975.*

*No. 23 AHLSTROM, E. H. and H. G. MOSER. Distributional atlas of fish larvae in the California Current region: Flatfishes, 1955 through 1960. 1975.*

## *Contributions*

This annual publication is a compilation of selected reprints authored by the Scripps faculty and staff. The *Scripps Institution of Oceanography Contributions* is avail-

able 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-075, La Jolla, California 92093.

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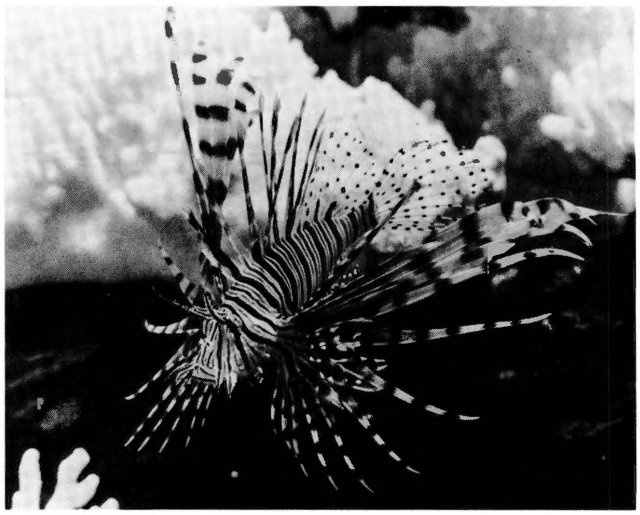

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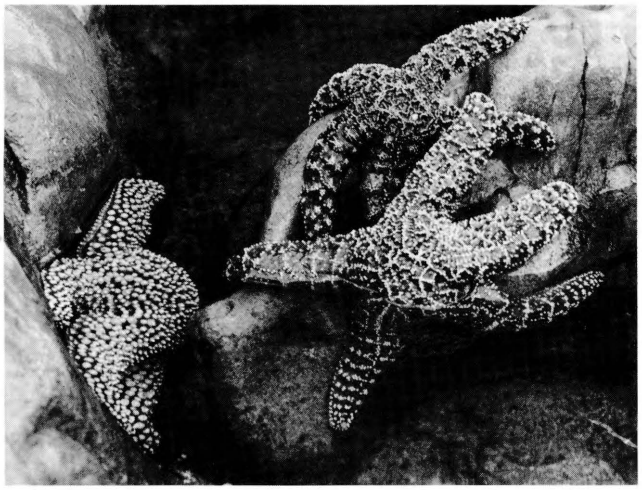

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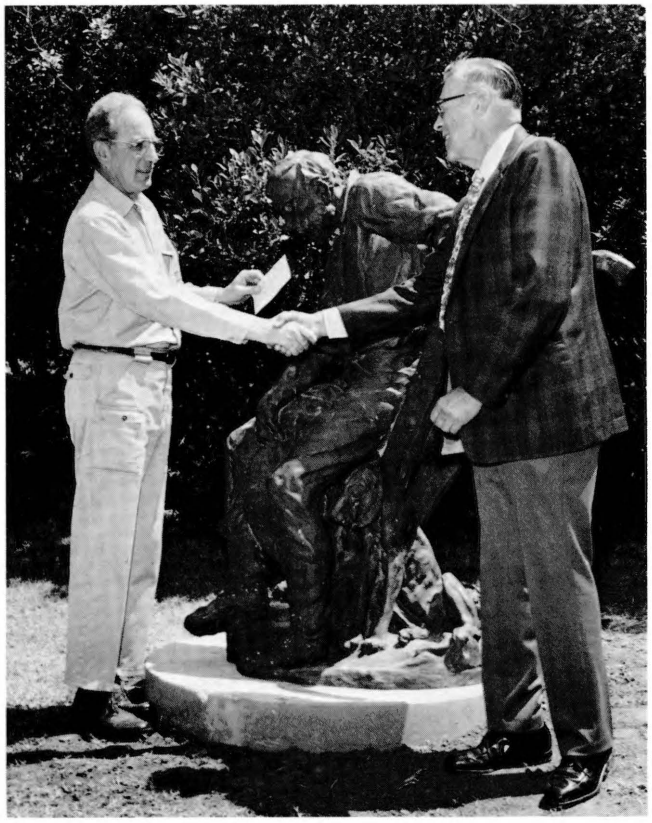

*Director Nierenberg (left) accepts bronze statue "The Ploughman," of George H. Scripps (background), from Robert P. Scripps, Balmorhea, Texas, great-nephew of George Scripps and grandson of E. W. Scripps, famed newspaper publisher. E. W. Scripps commissioned sculpture of his half-brother, George, by Arthur Putnam. The bronze, which stands six feet and bears Putnam name and date of 1910, depicts George's "moment of decision" as he rested on his plow on his Indiana farm to ponder whether to respond to his brother James's request for financial assistance from him and his sister, Ellen Browning Scripps, to help James's struggling newspaper. George's favorable reply led to vast newspaper empire created by E. W. Scripps and, eventually, to establishment of Scripps Institution of Oceanography. Statue is erected on lawn of Scripps campus.*

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| Frank E. Snodgrass | Institute of Geophysics and Planetary Physics | Geophysics |
| George N. Somero | Marine Biology Research Division | Marine Biology |
| Andrew Soutar | Marine Life Research Group | Paleontology |
| Fred N. Spiess | Marine Physical Laboratory | Marine Physics |
| Robert E. Stevenson | Ocean Research Division | Space Oceanography |
| Joan Godsil Stewart | Marine Biology Research Division | Biology |
| Robert H. Stewart | Institute of Geophysics and Planetary Physics | Oceanography |
| Charles K. Stidd | Ocean Research Division | Meteorology |
| Daniel H. Stuermer | Institute of Geophysics and Planetary Physics/ Deep Sea Drilling Project | Geology |
| Chih-Wu Su | Geological Research Division | Organic Chemistry |
| James J. Sullivan | Sea Grant Program | Economics |
| Peter R. Supko | Deep Sea Drilling Project | Marine Geology |
| Mia J. Tegner | Ocean Research Division | Marine Biology |
| Hans R. Thierstein | Geological Research Division | Geology |
| William H. Thomas | Institute of Marine Resources | Microbiology |
| Mizuki Tsuchiya | Institute of Marine Resources | Biological Oceanography |
| John E. Tyler | Visibility Laboratory | Physics |
| John L. Usher | Deep Sea Drilling Project | Paleontology |
| Shin-ichi Uye | Marine Life Research Group | Zooplankton Ecology |
| *Victor Vacquier | Marine Physical Laboratory | Geophysics |
| Charles W. Van Atta | AMES/Sea Grant College Program | Geophysical Fluid Dynamics |
| David J. Vanderah | Ocean Research Division | Chemistry |
| William G. Van Dorn | Ocean Research Division | Physical Oceanography |
| Elizabeth L. Venrick | Marine Life Research Group | Oceanography |
| Edith S. Vincent | Geological Research Division | Nannofossil Micro-Paleontology |

| | | |
|---|---|---|
| Benjamin E. Volcani | Marine Biology Research Division | Marine Microbiology |
| Thomas G. Warner | Marine Biology Research Division | Chemistry |
| + Bruce A. Warren | Department SIO | Deep Ocean Cicrulation |
| Ray F. Weiss | Geological Research Division | Geochemistry |
| Richard T. Wert | Ocean Research Division | Meteorology/Data Processing |
| Oscar E. Weser | Deep Sea Drilling Project | Marine Sedimentation |
| *Charles D. Wheelock | Institute of Marine Resources | Naval Architecture |
| Stanton M. White | Deep Sea Drilling Project | Sedimentology |
| Warren B. White | Ocean Research Division | Oceanography |
| Gerald L. Wick | Institue of Marine Resources | Physics |
| Donald W. Wilkie | Aquarium-Museum | Marine Biology |
| Gordon O. Williams | Institute of Geophysics and Planetary Physics | Geophysics |
| Peter M. Williams | Institute of Marine Resources | Biological Oceanography |
| Wayne H. Wilson | Visibility Laboratory | Hydrologic Optics |
| Clinton D. Winant | Ocean Research Division/ Sea Grant College Program | Oceanography |
| + Rudolf Winter | Ocean Research Division | Geophysics |
| Edward L. Winterer | Geological Research Division | Geology |
| A. A. Yayanos | Physiological Research Laboratory | Physiology |
| Bernard D. Zetler | Institute of Geophysics and Planetary Physics | Oceanography |
| *Claude E. ZoBell | Marine Biology Research Division | Marine Microbiology |

# Adjunct Professor Series
* Emeritus
+ Visiting/Postdoctoral Scholar
† Deceased


*Aquarium-museum summertime classes in oceanography offered a variety of experiences for young people during the year. High-school students participated in studies of natural history through skin diving. Graduate student Noël Davis (lower left) talks with the class before a dive. Younger students learned marine biology, ecology, and conservation. Their studies intertwined with crafts that demonstrated lessons or utilized marine materials. Youngsters (at lower left) create a macrame mobile with driftwood and shells they have gathered. Girl draws fish on sand (center photos) as another admires sand cast made from sand sketch. Teacher and students model clay octopuses (right photos).*

# *Appendix A*

**ASSOCIATE DIRECTORS**
R. L. Fisher
G. G. Shor, Jr.
F. N. Spiess

**DIRECTOR—DEAN**
W. A. Nierenberg

**DEPUTY DIRECTOR**
C. J. Merdinger

**ASSISTANT DIRECTORS**
J. D. Frautschy
G. L. Matson

## MAJOR ACADEMIC/RESEARCH DIVISIONS

GEOLOGICAL RESEARCH DIVISION
J. N. Brune

MARINE BIOLOGY RESEARCH DIVISION
F. T. Haxo

OCEAN RESEARCH DIVISION
C. S. Cox

MARINE PHYSICAL LABORATORY
F. N. Spiess

PHYSIOLOGICAL RESEARCH LABORATORY
A. A. Benson

VISIBILITY LABORATORY
S. Q. Duntley

DEEP SEA DRILLING PROJECT
M.N.A. Peterson

MARINE LIFE RESEARCH GROUP
J. L. Reid

ADVANCED OCEAN ENGINEERING LABORATORY
G. H. Fisher

## INSTRUCTION

GRADUATE DEPARTMENT OF THE SCRIPPS INSTITUTION OF OCEANOGRAPHY
F. N. Spiess, Chairman
M. M. Mullin, Vice-Chairman

APPLIED OCEAN SCIENCES
C. D. Winant

BIOLOGICAL OCEANOGRAPHY
R. R. Hessler

GEOPHYSICS
R. L. Parker

MARINE BIOLOGY
R. A. Lewin

MARINE CHEMISTRY
G. Arrhenius

GEOLOGICAL SCIENCES
E. L. Winterer

PHYSICAL OCEANOGRAPHY
R. S. Arthur

## UC INSTITUTES

INSTITUTE OF GEOPHYSICS AND PLANETARY PHYSICS
W. H. Munk, Associate Director
J. N. Brune, Associate Director

INSTITUTE OF MARINE RESOURCES
J. D. Isaacs, Director
Food Chain Research Group
Sea Grant College Program

## TECHNICAL SUPPORT

SHIP OPERATIONS AND MARINE TECHNICAL SUPPORT
R. L. Fisher

NIMITZ MARINE FACILITY
P. S. Branson

MARINE TECHNOLOGY GROUP
J. L. Abbott

SHIP SCHEDULER
R. B. Haines

## SCIENTIFIC COLLECTIONS

BENTHIC INVERTEBRATES
W. A. Newman

PLANKTONIC INVERTEBRATES
A. Fleminger

MARINE VERTEBRATES
R. H. Rosenblatt

GEOLOGICAL
W. R. Riedel

## PUBLIC SERVICE

AQUARIUM-MUSEUM
D. L. Wilkie

LIBRARY
W. J. Goff

PUBLIC AFFAIRS
R. N. Fuller

TECHNICAL PUBLICATIONS
K. K. Kuhns

## *Appendix B*
## SPONSORS OF RESEARCH AND GRADUATE INSTRUCTION

### STATE:
State of California
Department of Fish and Game
Department of Navigation and Ocean Development

### FEDERAL:
National Science Foundation
Department of the Navy
  Office of Naval Research
  Naval Supply Center
  Naval Undersea Center
Energy Research and Development Administration
Department of the Air Force
National Aeronautics and Space Administration
Department of Commerce
  National Oceanic and Atmospheric Administration
  National Marine Fisheries Service
Department of Defense
  Advanced Research Projects Agency
  Defense Mapping Agency
Department of the Interior
  Bureau of Mines
  Geological Survey
Department of Health, Education and Welfare
Environmental Protection Agency

### OTHER:
Alcoa Foundation
American Cancer Society
American Heart Association
American Metal Climax Foundation, Incorporated
AMOCO International Oil Company
ARCS Foundation
Atlantic Richfield Company
Atlantic Richfield Foundation
Stephen and Mary Birch Foundation, Incorporated
Chevron Oil Field Research Company
Cities Services Company
William L. Dowd Memorial Fund
EXXON Production Research Company
Foundation for Ocean Research
Cecil H. and Ida M. Green Foundation
Gulf Oil Corporation
The Helis Foundation
International Nickel Company
Kelco
Kennecott Copper Corporation
Kennecott Exploration, Incorporated
S. H. Kress Foundation
La Jolla Foundation for Earth Sciences
John B. McKee Fund
Mobil Oil Corporation
National Academy of Sciences
Navy League of San Francisco (Chester W. Nimitz Fund)
Occidental Petroleum
Ocean Management, Incorporated
Pacific Sierra Research Corporation
Elsa U. Pardee Foundation
Peterson-Silberman Fund
Helen Raitt Memorial Fund
Rockefeller Foundation
Science Applications, Incorporated
Ellen Browning Scripps Endowment Fund
Sea World Incorporated
G. D. Searle and Company
Shell Oil Company
Francis P. Shepard Foundation
A. P. Sloan Foundation
Société Nationale des Pétroles d'Aquitaine
Soil Research and Development Corporation
Seth Sprague Foundation
Sun Oil Company
Texaco Incorporated
Union Oil Company
United States Steel Foundation, Incorporated
Van Camp Foundation
Westinghouse Electric Corporation
World Meteorological Organization

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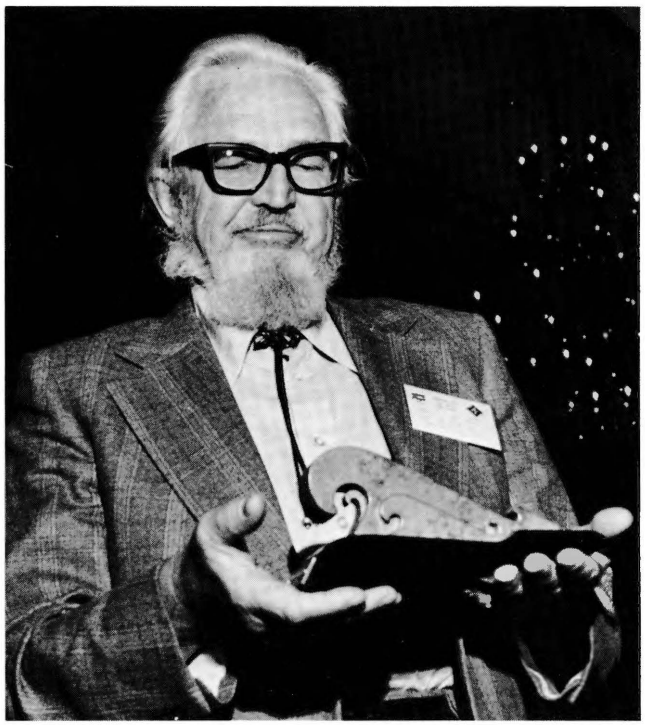
## *Appendix C*
## MAJOR AWARDS AND HONORS

Dr. Wolfgang H. Berger
  Named first recipient of the ARCS' (Achievement Rewards for College Scientists) Alumnus, *cum laude* Awards (or ARCS Alumnus of the Year).
Sir Edward C. Bullard
  Awarded the Royal Medal for important contributions in the physical sciences by Her Majesty, the Queen of England.
Dr. David Epel
  Received a John Simon Guggenheim Memorial Foundation Fellowship.
Dr. Frederick H. Fisher
  Elected member of the Council of the Acoustical Society of America for a three-year term.
David Gardiner, graduate student
  Named first recipient of the Carl L. Hubbs Sea World Fellowship in marine biology.
John D. Isaacs
  Received the Lockheed Award for Ocean Science and Engineering from the Marine Technology Society.
Julian A. Koslow, graduate student
  Received a Wib Chapman-Benny Schaefer Award from the Marine Technology Society.
Dr. Walter H. Munk
  Awarded the first Maurice Ewing Medal given jointly by the American Geophysical Union and the U.S. Navy. Received the Alexander Agassiz Gold Medal from the National Academy of Sciences. Elected foreign member of the Royal Society of London.
Dr. William A. Nierenberg
  Received the Compass Distinguished Achievement Award from the Marine Technology Society.
Dr. Robert L. Parker
  Received the James B. Macelwane Award from the American Geophysical Union.
Dr. William R. Riedel
  Received Honorary Doctor of Science, University of Adelaide.
James R. Stewart
  Received certificate of appreciation from the National Park Service's Horace M. Albright Training Center.
Victor Vacquier
  Received Medal Award from the Society of Exploration Geophysicists.
Dr. Elizabeth L. Venrick
  Appointed to the five-member California Fish and Game Commission for a five-year term by Governor Edmund G. Brown, Jr.



*Three persons from the institution received awards during the first combined Institute of Electrical and Electronics Engineers/Marine Technology Society's Ocean '75 meeting in San Diego in September 1975. Director Nierenberg (at right, top photo) accepts MTS Compass Distinguished Achievement Award from Dr. John C. Calhoun, MTS president, while John D. Isaacs admires bronze wave form representing the MTS/Lockheed Ocean Science and Engineering Award presented him by Dr. Calhoun. In third photo, graduate student Julian A. Koslow holds check for $200 presented by Dr. Robert B. Abel, director of National Oceanic and Atmospheric Administration's National Sea Grant Program and an MTS past president. Koslow was honored for his paper, "The Anatomy of a Modern Fishery: The Bering Sea Pollack Fishery." His was one of three MTS awards presented to students in memory of Drs. Wilbert M. Chapman and Milner B. Schaefer, both prominent in national and international ocean-fisheries affairs for some 40 years. Dr. Schaefer was director of the University of California's Institute of Marine Resources (IMR) and professor of oceanography at Scripps. Isaacs succeeded Dr. Schaefer as director of IMR.*

*Dr. Wolfgang H. Berger (at right), is congratulated by Dr. Lee DuBridge as first recipient of the ARCS Alumnus of the Year Award,* cum laude, *at science awards dinner of Los Angeles chapter, Achievement Rewards for College Scientists (ARCS), held in Los Angeles. Dr. Berger was an ARCS scholar in 1966 while he was a graduate student at Scripps. Dr. DuBridge is president emeritus of California Institute of Technology and was honored in 1967 as the Science Man of the Year by ARCS, a philanthropic organization.*

*Photo courtesy of ARCS*

# *Appendix D*

## RESEARCH VESSELS OF SCRIPPS INSTITUTION OF OCEANOGRAPHY

| | Alexander Agassiz | Alpha Helix | Dolphin | Melville | Ellen B. Scripps | Thomas Washington | FLIP | ORB |
|---|---|---|---|---|---|---|---|---|
| **Type:** | light freight | oceanographic research (biological) | oceanographic research | oceanographic research | offshore supply | oceanographic research | floating instrument platform | oceanographic research buoy |
| **Hull:** | steel | steel | aluminum | steel | steel | steel | steel | steel |
| **Year Built:** | 1944 | 1965-1966 | 1968 | 1969 | 1964-65 | 1965 | 1962 | 1968 |
| **Year acquired by SIO:** | 1961 | 1966 | 1973 | 1969 | 1965 | 1965 | 1962 | 1968 |
| **From whom acquired:** | State Educational Agency for Surplus Property | National Science Foundation | Robert O. Peterson | U.S. Navy | Dantzler Boat and Barge Co. | U.S. Navy | Gunderson Bros. Shipbuilding Co. | U.S. Navy |
| **Owner:** | University of California | University of California | University of California | U.S. Navy | University of California | U.S. Navy | U.S. Navy | U.S. Navy |
| **Length:** | 180′ | 133′ | 96′ | 245′ | 95′ | 209′ | 355′ | 69′ |
| **Beam:** | 32′ | 31′ | 22′ | 46′ | 24′ | 39′5″ | 20′ | 45′ |
| **Draft:** | 10′ | 10′5½″ | 7′ | 16′ | 6′ | 14′5″ | 11′/300′ | fwd. 4′10½″ aft 5′4½″ |
| **Displacement: Tons (Full):** | 869 | 512 | 120 | 2,075 | 234 | 1,362 | 1,500 (vertical) | 325 |
| **Cruising speed:** | 10 | 10 | 12 | 11 | 9 | 11.9 | varies [-1] | varies [-1] |
| **Range (miles):** | 4,000 | 7,200 | 1,700 | 9,181 | 5,100 | 10,000 | varies [-1] | varies [-1] |
| **Endurance (days):** | 22 | 30 | 6 | 41 | 14 | 36 | 30 | 30 |
| **Crew:** | 16 | 12 | 5 | 19 | 5 | 19 | 6 | 5 |
| **Scientific party:** | 15 | 12 | 7 | 30 | 8 | 23 | 10 | 10 |

[-1]Depends on towing vessel
Ship on inactive status: Gianna
Ship for short-term, local use: ST-908
NOTE: For metric conversion purposes, one foot equals 0.3048 meters; one mile equals 1.6093 kilometers; one pound equals 0.4536 kilograms; one short ton (2,000 pounds) equals 0.907 metric tons.

1975-76 Total Days at Sea: 1,074
1975-76 Nautical Miles Steamed: 100,427

# *Appendix E*
# DOCTOR OF PHILOSOPHY DEGREES AWARDED IN 1975-76 WITH TITLES OF DISSERTATIONS

**Earth Sciences**

Raymond P. Buland, "Retrieving the Seismic Moment Tensor."
Stephen P. Huestis, "Bounding the Thickness of the Oceanic Magnetized Layer."
Lawrence A. Lawver, "Heat Flow in the Gulf of California."
James H. Natland, "Petrologic Studies of Linear Island Chains: Part 1 — The Samoan Islands. Part 2 — The Line Islands."
Richard K. Nishimori, "The Petrology and Geochemistry of Gabbros from the Peninsular Ranges Batholith, California, and a Model for Their Origin."
John A. Orcutt, "Structure of the Oceanic Crust and Upper Mantle."
Michael S. Reichle, "A Seismological Study of the Gulf of California: Sonobuoy and Teleseismic Observations, and Tectonic Implications."
Bruce R. Rosendahl, "Evolution of Oceanic Crust."
Clark R. Wilson, "Meteorological Excitation of the Earth's Wobble."

**Marine Biology**

Michael A. Barnett, "Studies on the Patterns of Distribution of Mesopelagic Fish Faunal Assemblages in the Central Pacific and Their Temporal Persistence in the Gyres."
Raymond T. Bauer, "Antifouling Adaptations of Caridean Shrimp: Grooming Morphology and Behavior."
Douglas R. Diener, "Hermaphroditism in Fish: A Comparative Study of the Reproductive Biology and Endocrinology of the California Labridae."
Ronald A. Fritzsche, "A Revision of the Eastern Pacific Syngnathidae (Pisces: Syngnathiformes)."
James D. Hauxhurst, "Lytic Enzymes and the Production and Stability of Bacterial Endospores at Increased Hydrostatic Pressure."
Ron S. Nolan, "The Ecology of Patch Reef Fishes."
John S. Patton, "Comparative Studies of Triglyceride and Wax Ester Digestion in Fish and the Characterization of a Novel Nonspecific Triglyceride Lipase."
John S. Paul, "Photorespiration in Diatoms: Studies on Glycolic Acid Oxidation and Related Metabolism of Glyoxylic Acid."
Barbara B. Prézelin, "Characterization of Peridinin-Chlorophyll *a*-Proteins. Isolated from the Marine Dinoflagellates *Glenodinium sp.* and *Gonyaulax polyedra,* and their Role in Photosynthetic Light Adaptation."
James A. Raymond, "Adsorption Inhibition as a Mechanism of Freezing Resistance in Polar Fishes."
Harry F. Ridgway, "The Mechanism of Gliding Motility in *Flexibacter polymorphus.*"
Theodore C. Tutschulte, "The Comparative Ecology of Three Sympatric Abalones."

**Oceanography**
Manuel E. Fiadeiro, "Numerical Modeling of Tracer Distributions in the Deep Pacific Ocean."
Barbara Hickey, "The Pacific Equatorial Undercurrent — A Velocity and Hydrographic Section, A Study of the Relationship between its Driving Forces, and a Time Dependent Linear Model for its Zonal Velocity."
Cynthia L. Lee, "Biological and Geochemical Implications of Amino Acids in Sea Water, Wood, and Charcoal."
George S. Lewbel, "Sex Ratios in *Caprella gorgonia* (Crustacea, Amphipoda, Caprellidae)."
Stephen E. Pazan, "Deep Water Wave Breaking."
Lloyd A. Regier, "Observations of the Power and Directional Spectrum of Oceanic Surface Waves."
Richard L. Salmon, "Large Scale Air-Sea Interactions with a Simple General Circulation Model and The Equilibrium Statistical Mechanics of Quasi-geostrophic Flows."
Vernon P. Simmons, "Investigation of the 1 kHz Sound Absorption in Sea Water."
John T. Turk, "A Study of Diffusion in Clay-Water Systems by Chemical and Electrical Methods."

## MASTER OF SCIENCE DEGREES AWARDED IN 1975-76

**Marine Biology**
Bryan R. Burnett
Yolanda D. Montejano

**Oceanography**
Timothy Gerrodette
Roger P. Hewitt
Eduardo A. Valenzuela Ayala

## SIO GRADUATES 1975-76

**Student Name and New Position**
Michael A. Barnett
Engineering Division
Tetra Tech, Inc.
Solana Beach, California
Raymond T. Bauer
California Polytechnic State University
San Luis Obispo, California
Raymond P. Buland
Postgraduate Research Geophysicist
Institute of Geophysics and Planetary Physics — SIO
Douglas R. Diener
Marine Ecological Consultants
Solana Beach, California
Manuel E. Fiadeiro
Assistant Professor
Yale University
New Haven, Connecticut
Ronald A. Fritzsche
Chesapeake Biological Laboratory
Solomons, Maryland
James D. Hauxhurst
Department of Biology
University of Louisville
Louisville, Kentucky
Barbara M. Hickey
Assistant Professor
University of Washington
Seattle, Washington
Lawrence A. Lawver
Postgraduate Research Geophysicist
Marine Physical Laboratory — SIO
Cynthia L. Lee
Postdoctoral Fellowship
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts
James H. Natland
Assistant Research Geologist
Deep Sea Drilling Project — SIO
Richard K. Nishimori
Postdoctoral Fellowship
University of North Carolina
Chapel Hill, North Carolina
Ron S. Nolan
Pacific Reef Fish Research
Laboratory
Island of Hawaii
John A. Orcutt
Postgraduate Research Geophysicist
Geological Research Division — SIO
John S. Patton
Postdoctoral Fellowship
Department of Physiology
University of Lund, Sweden
John S. Paul
Postdoctoral Fellowship
Laboratory of Chemical Biodynamics
UC Berkeley
Stephen E. Pazan
Lockheed Ocean Laboratory
San Diego, California
Barbara B. Prézelin
Postdoctoral Fellowship
Department of Biological Sciences
UC Santa Barbara
James A. Raymond
Instructor
Moss Landing Marine Laboratories
Moss Landing, California
Lloyd A. Regier
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts
Michael S. Reichle
Centro de Investigación Científica y
Educación Superior de Ensenada
Ensenada, Baja California, Mexico
Harry F. Ridgway, Jr.
Postdoctoral Fellowship
Department of Biology
UC San Diego
Bruce A. Rosendahl
Assistant Professor
Duke University
Durham, North Carolina
Richard L. Salmon
Assistant Research Oceanographer
Ocean Research Division — SIO
Vernon P. Simmons
U.S. Navy — Underwater System Center
New London Laboratory
New London, Connecticut
John T. Turk
U.S. Department of the Interior
Geological Survey
Albany, New York
Theodore C. Tutschulte
Marine Biological Consultants
Costa Mesa, California
Clark R. Wilson
Assistant Professor
University of Texas
Austin, Texas

## *Appendix F*

# THE REGENTS OF THE UNIVERSITY OF CALIFORNIA

## REGENTS EX OFFICIO

Edmund G. Brown, Jr.
*Governor of California and President of The Regents*
Mervyn M. Dymally
*Lieutenant Governor of California*
Leo T. McCarthy
*Speaker of the Assembly*
Wilson Riles
*State Superintendent of Public Instruction*
Earl P. Willens
*President of the Alumni Association of the University of California*
Charles D. Field
*Vice President of the Alumni Association of the University of California*
David S. Saxon
*President of the University*

## APPOINTED REGENTS

Edward W. Carter
William E. Forbes
William M. Roth
Frederick G. Dutton
William K. Coblentz
DeWitt A. Higgs
Glenn Campbell
William French Smith
Robert O. Reynolds
Dean A. Watkins
Joseph A. Moore, Jr.
John H. Lawrence
William A. Wilson
Daryn S. Peeples

## PRINCIPAL OFFICERS OF THE REGENTS

Donald L. Reidhaar
*General Counsel*
Owsley B. Hammond
*Treasurer*
Marjorie J. Woolman
*Secretary*

## SYSTEMWIDE ADMINISTRATION

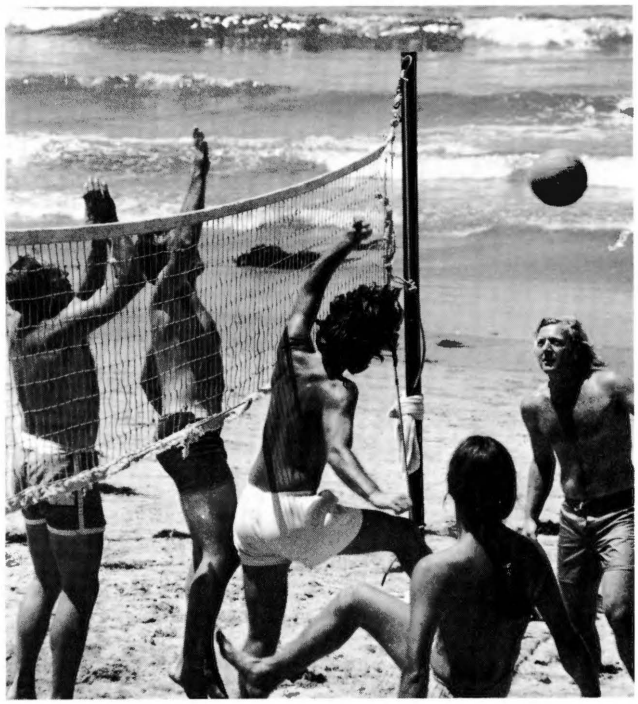
*President of the University*
David S. Saxon
*Vice President of the University*
Chester O. McCorkle, Jr.
*Academic Vice President*
Donald C. Swain
*Vice President — Academic and Staff Personnel Relations*
Archie Kleingartner
*Vice President — Agricultural Sciences*
James B. Kendrick, Jr.
*Vice President — Business and Finance*
John A. Perkins
*Vice President — University and Student Relations*
Robert L. Johnson
*University Provost*
Angus E. Taylor
*Special Assistant to the President for Governmental Relations*
Lowell J. Paige
*Assistant President — Coordination and Review*
Dorothy E. Everett
*Assistant President — Campus and Internal Relations*
Beverly Ruth Liss

## OFFICERS EMERITI

*President of the University, Emeritus, and Professor of Business Administration, Emeritus*
Clark Kerr
*Vice President of the University, Emeritus, and Dean of the College of Agriculture, Emeritus*
Claude B. Hutchison
*Vice President of the University, Emeritus*
Harry R. Wellman
*Vice President, Emeritus, and Secretary and Treasurer of The Regents, Emeritus*
Robert M. Underhill
*General Counsel, Emeritus*
Thomas J. Cunningham

## CHANCELLORS

*Chancellor at Berkeley*
Albert H. Bowker
*Chancellor at Davis*
James H. Meyer
*Chancellor at Irvine*
Daniel G. Aldrich, Jr.
*Chancellor at Los Angeles*
Charles E. Young
*Chancellor at Riverside*
Ivan Hinderaker
*Chancellor at San Diego*
William D. McElroy
*Chancellor at San Francisco*
Francis A. Sooy
*Chancellor at Santa Barbara*
Vernon I. Cheadle
*Chancellor at Santa Cruz*
Angus E. Taylor



*Graduate students and staff enjoy vigorous volleyball game during lunch.*

*Dr. Elizabeth L. Venrick*

*Appendix G*

# CURRENT FUNDS EXPENDITURES
## 1975-76

| | Scripps Institution of Oceanography | Institutes: Geophysics and Planetary Physics | Institutes: Marine Resources | Total |
|---|---|---|---|---|
| STATE OF CALIFORNIA | | | | |
| General | $ 4,642,274 | $ 182,040 | $ 307,920 | $ 5,132,234 |
| Other | 44,843 | — | 246,846 | 291,689 |
| Total State of California | 4,687,117 | 182,040 | 554,766 | 5,423,923 |
| UNITED STATES OF AMERICA | | | | |
| Grants— | | | | |
| Department of Defense-Air Force | — | 9,268 | — | 9,268 |
| Department of Health, Education and Welfare | 19,314 | 2,472 | 1,487 | 23,273 |
| National Aeronautics and Space Administration | 54,191 | 89,978 | — | 144,169 |
| National Institutes of Health | 242,462 | — | 5,036 | 247,498 |
| National Science Foundation | 5,884,668 | 486,532 | 338,062 | 6,709,262 |
| Other | 405,044 | 59,187 | 777,200 | 1,241,431 |
| Total Grants | 6,605,679 | 647,437 | 1,121,785 | 8,374,901 |
| Contracts— | | | | |
| Department of Defense | | | | |
| Air Force | 338,084 | — | — | 338,084 |
| Army | 10,277 | — | — | 10,277 |
| Navy | 5,647,657 | 414,944 | 5,162 | 6,067,763 |
| Energy Research and Development Administration | 208,608 | 71,278 | 380,348 | 660,234 |
| National Aeronautics and Space Administration | — | 11,907 | — | 11,907 |
| National Science Foundation | 13,684,556 | — | — | 13,684,556 |
| Other | 395,659 | — | 12,902 | 408,561 |
| Total Contracts | 20,284,841 | 498,129 | 398,412 | 21,181,382 |
| Total United States of America | 26,890,520 | 1,145,566 | 1,520,197 | 29,556,283 |
| ENDOWMENT FUNDS | 299,692 | 21,791 | 155,738 | 477,221 |
| GIFTS AND PRIVATE GRANTS | 1,249,261 | 114,837 | 111,196 | 1,475,294 |
| OTHER SOURCES | 65,183 | 2,380 | 9,718 | 77,281 |
| Total Current Funds Expenditures | $33,191,773 | $1,466,614 | $2,351,615 | $37,010,002 |

**UCSD**
University of California, San Diego
Code Q -036
La Jolla, Ca 92093

SECOND CLASS
POSTAGE
PAID
LA JOLLA, CA