

SIO
Scripps Institution
of Oceanography
Annual Report
1974

UCSD

UNIVERSITY OF CALIFORNIA, SAN DIEGO



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SCRIPPS INSTITUTION
OF OCEANOGRAPHY

ANNUAL REPORT
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Ending June 30, 1974





He was the first to culture marine organisms taken from depths as great as 10,000 meters . . . and has consulted with the National Aeronautics and Space Administration on extraterrestrial life. He took part in the famed *Galathea* 'Round-the-World Deep-Sea Expedition in 1951-52 . . . and was among the first to study problems of primitive life on the volcanic island, Surtsey, after it erupted off the coast of Iceland in 1963.

He's Dr. Claude E. ZoBell, professor emeritus of marine microbiology, who, after 42 years with Scripps, still reports daily to his Ritter Hall laboratory, working quietly beside his wife and colleague, Jean, and completely unassuming in the face of his many contributions to science which have brought him international recognition. He is shown here in his laboratory inspecting a flask of nutrient agar for autoclave sterilization.

A native of Utah, where he was born in 1904, Dr. ZoBell was trained in medical bacteriology. He took his B.S. (1927) and M.S. (1929) degrees in bacteriology from Utah State University in Logan (which later was to declare him a distinguished alumnus), and his doctorate in medical bacteriology from the University of California, Berkeley, in 1931. His first position with UC was with the Hooper Foundation for Medical Research in San Francisco, where he served for several months before joining the Scripps faculty on January 1, 1932.

Writing in the *American Society for Microbiology News*, a colleague noted that, although he had been trained for medical bacteriology "and had scarcely seen the ocean, Dr. ZoBell came to Scripps Institution of Oceanography to learn about the microbiology of the sea. He was immediately challenged with the proposition that bacteria found in the sea were mainly from the air and terrestrial runoff. As he began to deter-

mine the extent to which bacteria are active in the open ocean and to assess their possible importance as geochemical agents, the field of marine microbiology was gradually founded as an independent science."

His more than four decades of research included at-sea work on ten expeditions and the authorship of a textbook and more than 250 technical articles summarizing the results of his investigations on the importance of bacteria in the sea and their action on petroleum. He is credited with these major discoveries: methods for studying deep-sea microbes, the relationships of microorganisms to solid surfaces, biological effects of high hydrostatic pressures, the role of microorganisms in the formation and transformation of petroleum, 65 new species of marine bacteria, and the occurrence of living organisms in some of the greatest-known ocean depths (7,000 to 11,000 meters).

He holds emeritus memberships on many local, state, national, and international scientific organizations, in addition to numerous honors ranging from a Congressional citation for service as a Judge for the Petroleum Engineers' Environmental Control Development Program to membership on the Joint U.S.-U.S.S.R. Environmental Agreement Working Committee on Oceanic Water Pollution.

Despite all the honors and accolades, however, he counts as his greatest thrill being aboard the Danish R/V *Galathea* in 1952 as crew members winched up sediments from the Philippine Trench which shortly he had under microscopes and then divided into 50 containers for the start of what became historically the first culturing of organisms taken from the deep ocean. Fifteen years later he still was growing them in the four remaining containers of the original 50, kept under pressure and temperatures identical to those under which they were taken.

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Glasheen Graphics

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INTRODUCTION

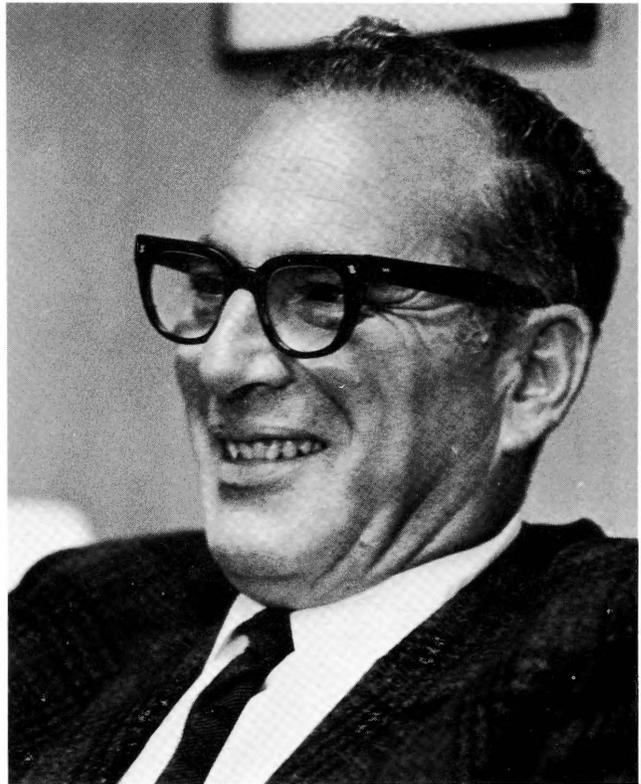
This has been a year full of changes for Scripps Institution of Oceanography. An increasing size of operation and also the increasing complexity of dealing with Washington have dictated a more formal management structure. This need resulted in the appointment of an Associate Director for Administration, Warren Levin, together with additional supporting staff. They began functioning in January, 1974, and the improvement in the Institution's operations was evident almost immediately.

In June, the announcement was made of the appointment of Dr. Charles J. Merdinger as Deputy Director. This marked the culmination of a year-long search. Dr. Merdinger brings with him a distinguished career in the military, in education, and in engineering.

Also initiated during the year was a major reorganization the principal factor of which was the grouping of ship operations and shipboard services, including the Shipboard Computer Group and marine technicians, plus scientific collections, into one major unit. Dr. Robert L. Fisher now is Associate Director supervising these operations.

I find this a difficult year to describe in this note; so many things have happened. For one, we celebrated the Institution's seventieth birthday. For another, construction of two buildings was started: the Marine Biology Research and Instruction Building and the NORPAX Building. Beyond these was the dedication of the new pier at Nimitz Marine Facility. We are very grateful to the National Science Foundation for their support and recognition of this need. The old pier, built with two surplus barges, served very well, but was a recognized temporary solution from the very beginning.

The research programs at Scripps continue to gain, largely as a result of the activities of younger members of the staff and particularly because of the great graduate students the Institution is attracting. (A question often posed is that with respect to job openings for our graduates. The answer seems to be positive, at least at the present time.) The research activities are described in some detail in this report, as usual, but two are noteworthy as an indication of the broadening of the overall program. One was Professor Bada's announcement of the dating of a La Jolla skull at nearly 50,000 years by his racemization technique. Another was the spate of stories on Jerry Namias' climate predictions sought by the government to help deal with the oil and food crises. His work, of course, is an outgrowth of NORPAX, the North Pacific Experiment, and is a field that will grow.



This year saw the passing of two close associates of Scripps. Maxwell Silverman died unexpectedly just after transferring his headquarters to Washington. He was closely identified with the development of the nation's oceanographic vessels. The great loss to the Institution was the passing of Carl Eckart, one of the foremost figures in physical oceanography in the postwar era. His accomplishments were many, and we are particularly grateful to him as the former Director who gave the Institution a revitalized start after World War II and was a major figure in the formation of the new University campus at San Diego.

A two-months' exhibition of the late Ron Church's underwater photographs was held in the Vaughan Aquarium-Museum. Thousands of visitors attended that exhibition, a fitting memorial for this noted pioneer in underwater photography.

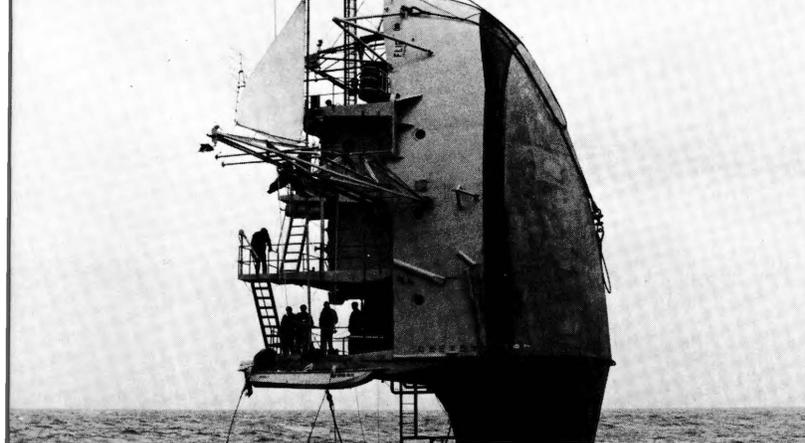
By normal measures, the Institution continues to prosper. The "rolling readjustment" I have referred to in earlier reports continues in response to the sharp changes in technological interests externally imposed. As would be expected, the basic research program is essentially unchanged, but the sponsors often are, and so are the structure and groupings. The staff is clearly deeply concerned about the organization of research being dictated largely by Washington, and the possible effects of grouping small programs into larger ones. As a result, a series of conferences and exchanges is planned to ventilate these and related issues. This activity could be vital in preserving basic research efforts.

William A. Nierenberg

William A. Nierenberg, Director
Scripps Institution of Oceanography



Dr. Robert Marshak, left, president of City College of New York, examines 25-pound specimen of deep-ocean basalt during visit with Director Nierenberg, an alumnus of CCNY. The geologically Recent basalt, perhaps 10,000 years old, was dredged at depth of a mile-and-a-half from crest of submerged mountain chain, the East Pacific Rise, 400 miles southwest of Acapulco, Mexico, during Scripps's 1969 Quebrada Expedition.



R/P FLIP

SEAGOING OPERATIONS

Nimitz Marine Facility and the Fleet

Scripps Institution operated seven research vessels, two research platforms, and a utility cabin cruiser during Fiscal 1973-74. These included R/V *George Melville*, R/V *Thomas Washington*, R/V *Alexander Agassiz*, R/V *Alpha Helix*, R/V *Oconostota*, R/V *Ellen B. Scripps*, R/V *Dolphin*, R/P FLIP, R/P ORB, and the cruiser *Gianna*. R/Vs *Melville*, *Thomas Washington*, *Alpha Helix*, and *Alexander Agassiz* were engaged in major expeditions. The fleet spent a total of 1,215 days at sea and traveled 147,979 nautical miles.

R/V *Melville* left San Diego on GEOSECS Pacific Expedition August 22, 1973, on the first of ten legs, with Dr. Harmon Craig as chief scientist. The nature of the expedition is detailed below and in the Research Activities section. The *Melville*, which returned to home port in June of 1974, spent 258 days at sea and logged 35,176 nautical miles.

R/V *Thomas Washington* spent the greater part of Fiscal 1973-74 engaged in Tasaday Expedition, for which she had left San Diego June 4, 1973. Biological, chemical, geological, and geophysical investigations comprised the major effort of the expedition, many results of which are described below. The ship returned to Nimitz Marine Facility March 18, 1974.

Dit-Tow Expedition off San Diego, the ship's final trip of the year, tested a new Deep-Tow photo system. R/V *Thomas Washington* spent some 247 days at sea and covered 39,848 nautical miles.

The first four months of the year found R/V *Alexander Agassiz* working a series of short cruises involving geochemical water sampling, gravity coring, deep light measurements, and biological studies off San Diego. After Climax Expedition and before she went into the shipyard in December, the ship finished the last two legs of an expedition to La Paz, Baja California, with coring, hydro, and net tows. The M-15 Expedition in March involved the study of rattails and sable, followed by studies off San Diego; and San Felipe, Santa Rosalia, and La Paz, Baja California. The first and second legs of Krill Expedition in May took the ship to Acapulco, Mexico, for plankton, hydrography, and fish paleontology work. R/V *Alexander Agassiz* was 148 days at sea and she tracked 20,007 nautical miles.

The R/V *Alpha Helix* departed San Diego in July, 1973, for its four-month Bering Sea Expedition, visiting such Alaskan ports as Cold Bay, Dutch Harbor, Nome, and Teller. The Kona Expedition followed in October, and after Climax Expedition in December, the ship headed south for three legs of the Baja Expedition. Dramamine II Expedition began in April with a cruise to the North Pacific Gyre. The remaining few months, May-July, 1974, found the ship returning north for Aleutian Trench operations and Bering Sea studies. Results of all these investigations are described below. R/V *Alpha Helix* spent some 245 days at sea and covered 26,913 nautical miles.



R/P ORB

R/V *Oconostota* made 15 short trips in the San Diego area during the first four months of the year. The operations included towing ORB; mid-water trawl, water sampling, and gravity core work; and a 12-day trip to Guadalupe, Mexico, for fish collecting. The ship was berthed at Nimitz Marine Facility in December, 1973, and stayed in port until a pre-cruise shakedown test of hydro and dredge winches in June, 1974. The ship was 47 days at sea and she logged 3,376 nautical miles.

R/V *Ellen B. Scripps* completed 29 trips during the year, most of them for durations of five days or less. Operations included testing electronic equipment of various types, seismometer deployment, stable floating platform model operations, aircraft check of a radio buoy, testing of drogue buoys and bottom seismometer buoys, launching and tracking of an instrument capsule, taking BT, STD, and bottle casts; deploying net tows, ocean bottom seismometers, and freefall instruments; seismic surveys, core and water sampling, testing of surface drogues, refraction runs, a student cruise, and the launching and tracking of a deep-sea capsule. The vessel spent 109 days at sea and tracked 9,912 nautical miles.

The R/V *Dolphin*, acquired in January, 1974, was used for biological and geophysical work in the Gulf of California. She spent 79 days at sea and covered 6,377 nautical miles.

R/P FLIP took part in the NORPAX Pole Expedition (*q.v.*) in January, 1974, out of Honolulu. After being towed back to San Diego by the U.S. Navy, FLIP operated off San Diego in studies that included acoustical work, tests of mooring lines, and the measurement of internal waves. FLIP spent 45 days at sea and was towed a distance of 4,724 nautical miles.

R/P ORB was operated in the San Diego area commencing in November, 1973, in conjunction with Naval Undersea Center tests. In March, 1974, she carried out pressure tests and water sampling, followed by the testing of a large acoustical array. ORB spent 28 days at sea and was towed a distance of 515 nautical miles.

The *Gianna* was acquired in February, 1974, and was used mostly for short-range operations in the San Diego area that included testing of scientific gear, surveying marine birdlife, transferring gear and personnel to R/V *Thomas Washington*, and testing of a digital recording system for seismic refraction. The *Gianna* spent nine days at sea and logged 1,190 nautical miles.

Major Expeditions

Scientific Programs of R/V Alpha Helix

The program and the scientific supporting operations of R/V *Alpha Helix* are directed by Dr. Walter F. Gary of the Physiological Research Laboratory. The laboratory ship *Alpha Helix*, as a National Oceanographic Facility, is usually engaged in studies of experimental biology by scientists from throughout the United States and foreign countries. A brief account of the operations and research activities of the *Alpha Helix* during 1973-74 appears earlier in this section. A booklet describing the ship and her program, and containing the abstracted field reports of studies carried out in 1972-74, may be obtained by contacting the *Alpha Helix* office in the Physiological Research Laboratory.



R/V Oconostota



R/V Alpha Helix

Bering-Chukchi Seas and Kona Coast Expeditions

Alpha Helix returned to the Nimitz Marine Facility December 18, 1973, to conclude a five-month, 14,000-nautical-mile expedition into the Bering and Chukchi seas and off Hawaii's Kona Coast.

The Bering and Chukchi sea work centered around biomedical investigations of northern species of seals and other marine mammals, and the Kona Coast studies were devoted to biochemical investigations of deep-sea fishes.

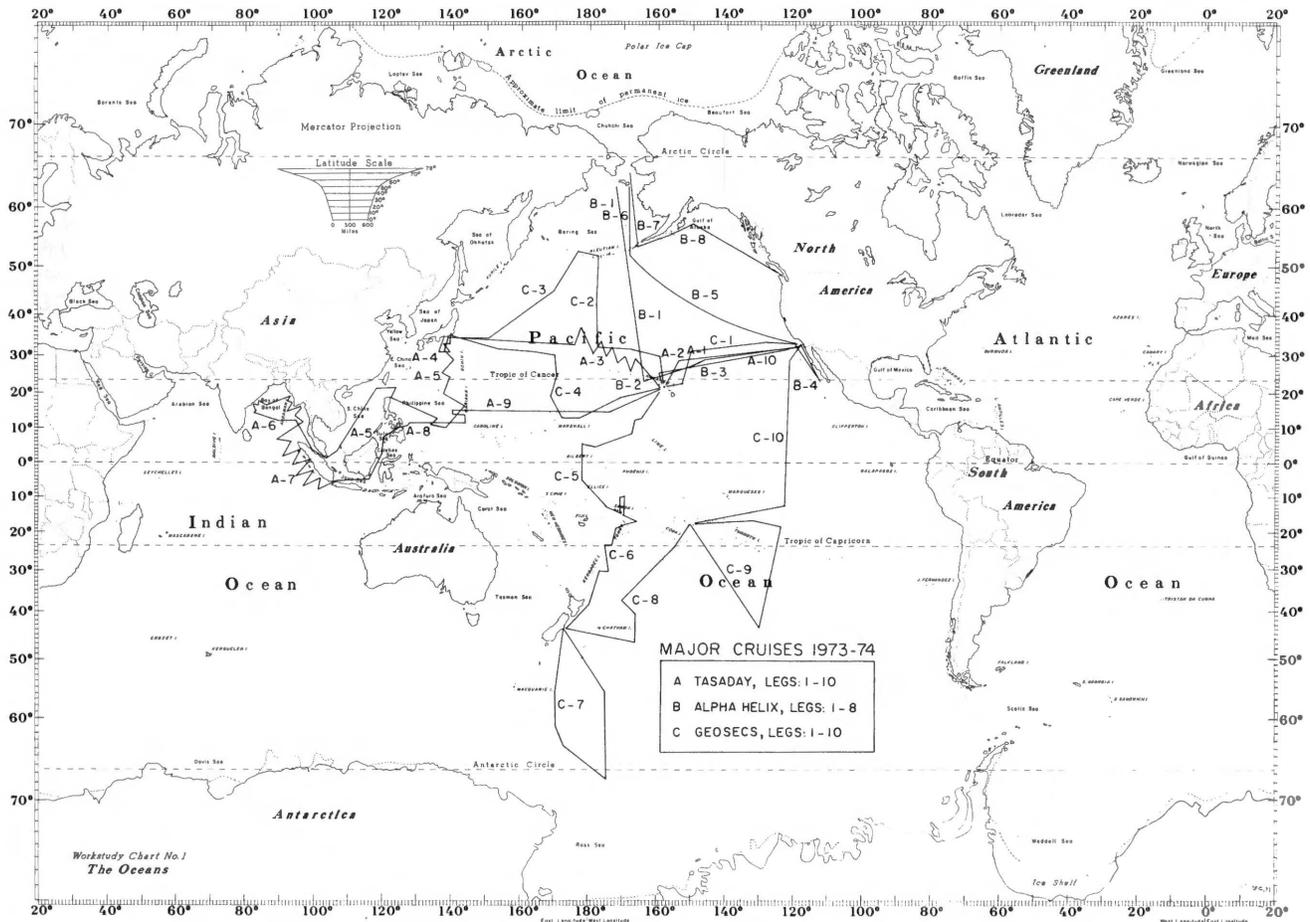
The expedition work, including Honolulu-San Diego en route studies of phytoplankton and zooplankton, was funded by the National Science Foundation. Alpha Helix is a national facility sponsored by NSF and operated by Scripps.

The vessel left San Diego July 9, 1973, and Robert B. Haines and Garrett S. Coleman shared captain's duties during the expedition.

Dr. Robert W. Elsner, formerly of Scripps and now professor of physiology at the University of Alaska's Institute of Marine Science, Anchorage, directed the Bering and Chukchi seas studies.

He said the seal investigations focused on the "unique diversity and abundance of marine mammals in the Bering and Chukchi seas, which form the marine frontier between Alaska and Siberia. Intense new research interest is being directed toward the study of marine mammals, and that region has a far greater concentration of such animals than any other American shoreline. In fact, it has one of the richest marine mammal concentrations in the world."

Dr. Elsner said the American people and Congress showed their interest in and concern for those species, for their conservation, and for an understanding of their natural history, by the passage of the Marine Mammal Protection Act of 1972.



"The continuing research is expected to provide new information about the biological bases for the adaptation of seals and walrus to cold marine environments," he said.

"There is also special interest among medical researchers in the unique opportunities for studies of adaptations that are natural for some marine mammals and impossible for human beings and, therefore, are useful for providing new understanding of disease in human beings."

Scientists from the University of Alaska, the Alaska Department of Fish and Game, and from the Soviet Union participated in the studies of the biology of the northern seals.

Other scientists from the University of Alaska, UC-San Diego Medical School, and UC-Davis investigated lung physiology and kidney and cardiovascular functions of the seals, and other scientists studied the physiology and biochemistry of the seals during their diving maneuvers and also their adaptation to cold. Preliminary information was brought back by UCSD Medical School scientists concerning lung functions of the northern seals that could be useful in treating respiratory distress syndromes in newborn babies.

Scientists working off the Kona Coast studied the biochemical and biophysical processes of benthic fishes, focusing on their unique adaptations to conditions of high pressure and low temperatures. Paul Dreizen, M.D., of the Downstate Medical Center of New York, in Brooklyn, said the studies were done on fishes recovered at depths of 1.6 to 3.2 km, where the fishes live at pressures approximately 200 times greater than atmospheric pressures and at temperatures close to freezing.

He said that 21 fishes were recovered in 80 deployments of the Scripps-developed free-vehicle system. The fishes included four species, two of which Dr. Dreizen said are comparatively rare and one of which appears to be a new species.

"Major aspects of the Kona research involved studies of metabolic regulatory enzymes, hemoglobin, muscle proteins, contractility, and the swim bladders of the fishes," Dr. Dreizen said.

"Some of these proteins are quite difficult to study, since they undergo rapid denaturation of the fish. Consequently, laboratory work had to be initiated aboard the ship promptly after recovery of the fishes, and methods were devised so in a number of instances, studies could be done on the critical enzyme system. A considerable amount of raw data were obtained, much of which remains to be analyzed by the scientists in their home laboratories. According to preliminary results, several of the protein systems show adaptations at the molecular level to conditions of temperature and pressure. Enzymatic properties vary in the different fishes that were studied, and it would appear that adaptations may occur by one of several mechanisms."

Twenty scientists participated in the Kona studies, including representatives from Scripps Institution, the University of British Columbia, the State University of New York, the University of Illinois, the University of Texas, the Carnegie-Mellon University, and the University of Hawaii.

Dr. Michael M. Mullin headed a scientific party that boarded the ship in Honolulu for San Diego for en route studies of the nutrient dynamics of the uptake rates of nitrogen, phosphorous, and silicon by phytoplankton; the excretion of nitrogen and phosphorous by zooplankton, and the vertical distribution of phytoplankton in the upper 500 m of the ocean. They also isolated phytoplankton clones for culturing.

University of Arizona scientists studied the polyamine distribution in marine invertebrates as the ship sailed toward San Diego, and UCLA scientists conducted controlled experiments regarding the ability of tube-nosed birds, such as shearwaters and petrels, to detect odor sources in the open ocean.

R/V *Thomas Washington*



Baja Expedition

During a two-month period early in 1974, a team of biochemists led by Dr. L. P. Hager of the University of Illinois analyzed life forms for the presence of organic halogen compounds and antimicrobial activity in extracts prepared from the organisms. The research team found that organic halogen compounds were widely distributed and abundant in the marine organisms studied. Of the approximately 1,000 species tested, 275 types of marine invertebrates and algae contained significant quantities of naturally occurring organic halogens in their lipids. Extracts from 160 species showed antimicrobial activity, an extremely high percentage of activity from an antimicrobial screen. In addition, a strong correlation was apparent between the presence of organic halogens and antimicrobial activity in the organisms.

North Pacific Expedition

Scientists headed by Dr. Mullin participated in this cruise during the spring of 1974, the last of a series of research efforts to investigate the structure and dynamics of plankton in the central gyre of the North Pacific. The design of the sampling program was based on past cruises, during which a rectangular grid of stations approximately 16 km apart generally had been sampled. During the effort this year, similar samples were taken following a shallow drogue, to see whether variability would be reduced if a "patch" of water at one depth were followed through time.

The mixed layer was initially considerably more shallow than at other times of the year, and appeared to deepen because of rough weather during the cruise. The standing crop of phytoplankton was higher than on previous cruises, and the deep chlorophyll maximum layer was broader than usual. The standing crop of zooplankton also seemed to be high, but the concentrations of nutrients were not anomalous.

Bering Sea Expedition

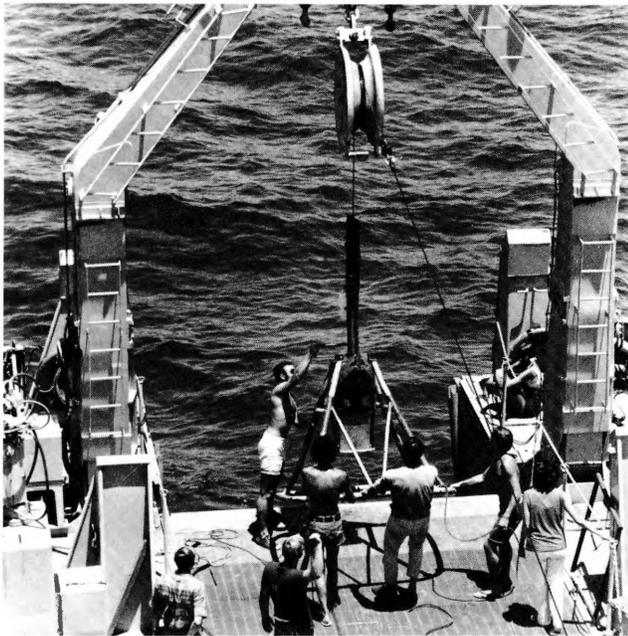
During a two-day period for ship transit from Hawaii to Alaska preceding this expedition, Dr. A. Aristides Yayanos and his associates field tested a device in the Aleutian Trench designed to retrieve amphipods under their *in situ* conditions of temperature and pressure.

In the Bering Sea work, from May-July, 1974, scientists led by Dr. Vera Alexander of the University of Alaska investigated the processes of primary productivity and transfer of organic matter to pelagic grazers. The near-ice zone was selected as the environment of intensive investigation. The experimental design involved carrying out zooplankton grazing experiments in large-volume containers on shipboard, obtaining a rate of carbon (chlorophyll) removal per zooplankton biomass, and relating this back to *in situ* rates by obtaining information on chlorophyll and zooplankton standing stocks. Maximum chlorophyll concentrations in the near-ice region occurred in the bottom layers below 20 m.

Data from the following types of experiments carried out on the *Alpha Helix* are currently being analyzed: tracer experiments using nitrogen-15-, carbon-15-, and carbon-14-labeled phytoplankton cultured by enrichment techniques, tracer experiments on the effects of zooplankton grazing pressure on nitrogen regeneration and nitrogen assimilation by phytoplankton, and the interaction of trace metals as well as the production and measurements of trace metal distribution.

R/V *Ellen B. Scripps*





Graduate student Charles Adelseck puts safety pin in place to prevent pre-tripping of box corer before it is launched from R/V *Melville* during *Benthiface Expedition* off Mexico. Pin is removed at time corer is manipulated overboard. Left to right are graduate student Steven Hartzell; resident technician Robert C. Wilson; graduate student Rodey Batiza; Dr. Wolfgang H. Berger, chief scientist; graduate student Tom Johnson; Dr. Miriam Kasner, geologist; and, right rear, graduate student Sharon Stonecipher.

Tom Walsh

GEOSECS Pacific

Scientists have confirmed that cold and dense Antarctic Bottom Water flows northward into the deep Pacific Ocean beneath a 10-million-square-kilometer sloping surface called the "benthic front," which is similar to weather fronts in the atmosphere.

Investigators participating in the 35,000-nautical-mile, 10-month, GEOSECS Pacific Expedition that ended in San Diego on June 10, 1974, said that the "front" exists not only south of the equator but also in the Northern Hemisphere.

Putting into Scripps's Nimitz Marine Facility, R/V *Melville* was loaded from bow to stern and below decks with thousands of seawater samples taken at nearly 150 work stations, and at depths ranging from sea surface to sea floor and extending from the Bering Sea to Antarctica. Capt. Alan W. Phinney was master of the ship for the entire cruise.

Average depth of the work stations in GEOSECS Pacific was about 5,000 m. Of the nearly 150 stations, roughly 40 were "large-volume" stations at which about 18,000 liters of seawater were collected per station. Roughly a third of that water was brought back to Scripps aboard *Melville* for distribution to laboratories throughout the world. The other two-thirds were returned to the ocean after shipboard analysis or processing to extract dissolved constituents. Underway measure-

Cabin Cruiser *Gianna*

ments of surface water and atmospheric properties also were made.

Melville's arrival marked the completion of the second phase of GEOSECS (Geochemical Ocean Sections Study), man's most intensive chemical investigation of ocean circulation and mixing processes. The study was funded by the National Science Foundation as part of the International Decade of Ocean Exploration.

GEOSECS' first phase was a similar investigation of Atlantic waters that ended in April, 1973, when R/V *Knorr* berthed at Woods Hole Oceanographic Institution, Woods Hole, Mass., after nine months at sea.

New Understanding of Benthic Front

"GEOSECS Pacific provided refined observations and a new understanding about the benthic front," said Dr. Harmon Craig, chief scientist on two of the cruise's ten tracks and a member of the Executive Committee of the GEOSECS Scientific Advisory Council.

"The front does, in fact, exist in the Northern Hemisphere, and we observed its transition across the equator from a surface that dips—or slopes downward—to the northeast in the Southern Hemisphere, to a surface that dips to the northwest in the Northern Hemisphere, instead of toward the northeast, as had been previously supposed.

"The front begins about 3,200 km east of New Zealand at a depth of about 2,500 m, and extends northward, marking the boundary between two water masses, the Central Pacific Deep Water and the Antarctic Bottom Water.

"Beneath the front, Antarctic Bottom Water flows past New Zealand toward the deep basins of the Pacific. The frontal surface continues to deepen toward the north until it disappears by mixing between the two water masses. The last region in which it can be detected is in the latitude of Hawaii."

The location and extent of the front were determined from measurements of the temperature and salinity of the seawater and its oxygen and nutrient content, especially silica.

According to earlier hypotheses, the influx of Antarctic waters into the deep Pacific came primarily from a narrow and comparatively high-velocity western boundary current that separates from the eastward Circumpolar Current and swings north along the western edge of the South Pacific.

Dr. Ray F. Weiss, chief scientist for Leg V of the expedition, explained that the time scale of water flow and oceanic mixing within the deep Pacific basins is on the order of 1,000 years.

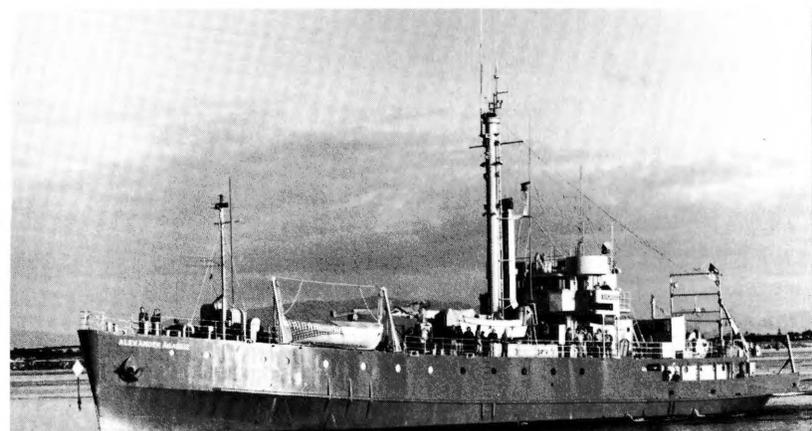
'Tracers' Utilized in Research

In many cases, he said, to determine the rate of most of these processes by direct measurement is almost impossible because of their slowness. That is why "tracers" such as natural radioisotopes—with half lives of the same time scale—were sampled during the expedition to provide new knowledge of Pacific circulation patterns.

"Also," Dr. Weiss said, "the dissolution of particles that fall from the surface layers, either in the form of the remains of organisms or as contaminated material transported by the wind and by surface currents, strongly influences deep-water chemical and radioisotopic composition.

"Because of this interaction, the GEOSECS studies of particulate matter are essential to our understanding of the circulation and mixing of the deep sea."

R/V *Alexander Agassiz*

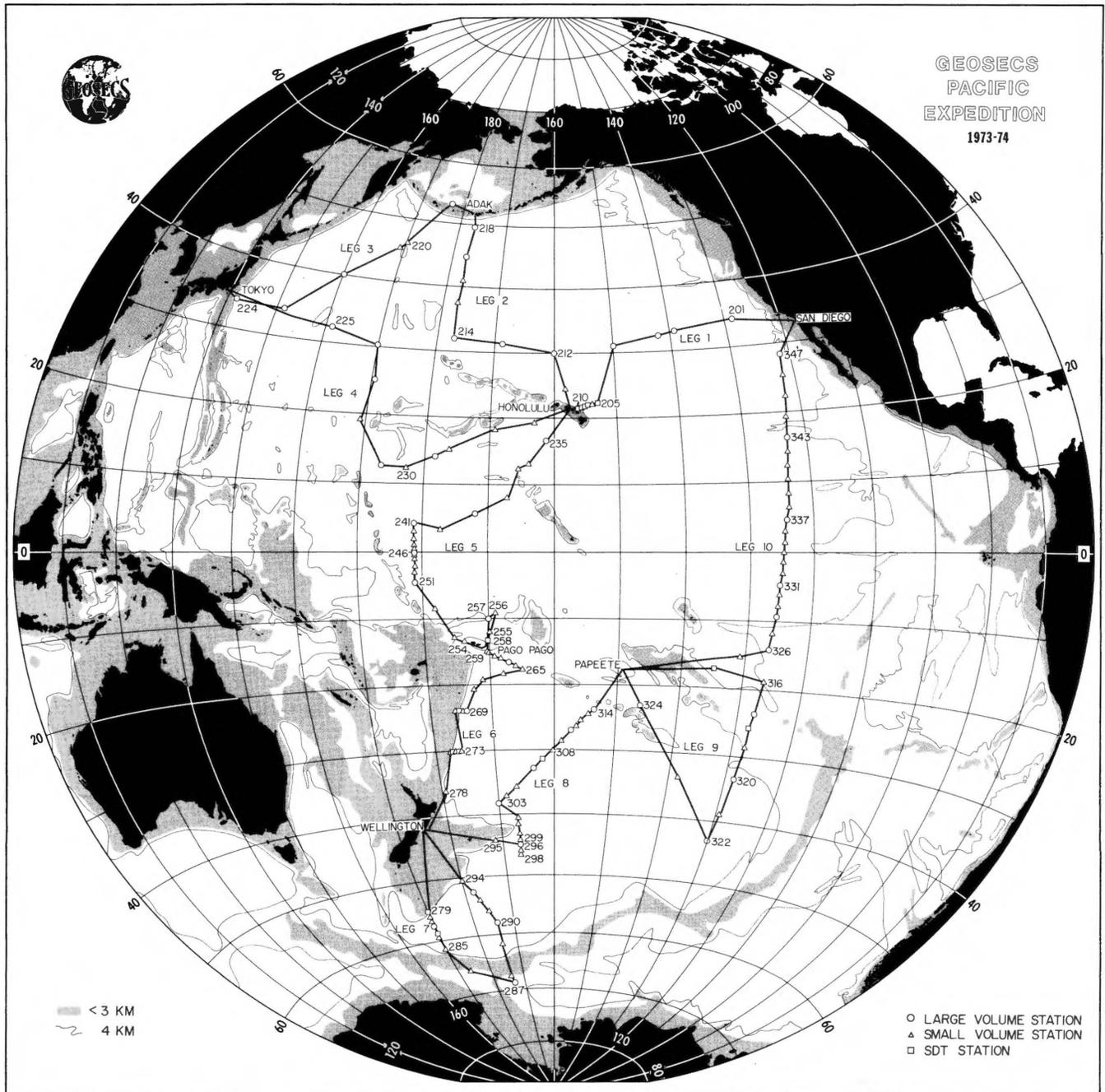




R/V *Dolphin*



R/V *George Melville*





The Institution's new Nimitz Marine Facility Pier is often a beehive of activity. At the 365x50-foot concrete pier is, right center, R/P FLIP, with the University of Hawaii's R/V Moana Wave just behind her. At left center is R/V Melville, with the Southwest Fisheries Center's R/V David Starr Jordan outboard her. In center is R/V Thomas Washington. Funded for the most part by the National Science Foundation, the \$854,100 addition to the now \$2-million facility includes the new pier and a 135-foot marginal wharf extension, out of the picture at left. Service mounds on the new pier provide sewer and bilge-water connections, telephone jacks, compressed-air outlets, and a fresh-water supply. Cylinder in foreground is a bilge-water holding tank. Pier is one of two in San Diego with completed sewer connections. Artistic camera view shows initial dredging for pier and marginal wharf. Third photo was taken as Director Nierenberg watched Mary Johrde, Washington, D.C., head of NSF's Office of Oceanographic Facilities and Support, break bottle of champagne on pier mooring bitt during dedication ceremonies March 14, 1974. R/V David Starr Jordan is now regularly berthed at Nimitz, and other institutions and federal agencies berth their ships on a space-available basis.

Dr. Craig said much of the success of GEOSECS Pacific will come from correlating the results of many different measurements made on thousands of water samples returned from *Melville* to participating university laboratories in this country and abroad, with hydrographic measurements made aboard ship.

The laboratory measurements include those of natural radioisotopes as well as those radioisotopes distributed in the environment by man through the testing of nuclear weapons.

"Weapons tests have introduced to the surface water fission and nuclear products, such as radiostrontium and cesium, tritium, and man-made carbon-14, that gave the scientists nuclear 'tags' allowing them to measure the rate of downward mixing from surface to intermediate waters," Dr. Craig said.

In deep and bottom waters, the investigators are using concentrations of natural radioactive isotopes radium-226, silicon-32, and cosmic-ray-produced carbon-14 to study vertical and horizontal mixing in the ocean.

Dissolved Gases Studied

A major GEOSECS Pacific study is that of dissolved gases, including helium-3 and helium-4, released from the earth's interior. "Helium-3, in particular, is an important tracer of gases that were entrapped during the formation of the earth some four-and-one-half-billion years ago, and that are now being released into the deep oceans through sea-floor

spreading and other geologic processes," Dr. Craig said.

"In the deep ocean, the helium-3/helium-4 ratio is found to be up to 40 percent greater than in the atmosphere. Results from earlier Scripps cruises showed that this ratio is highest over the East Pacific Rise, off Central America, and that this excess helium-3 is thought to represent primeval helium-3 escaping from the interior of the earth during new crust formation and sea-floor spreading."

GEOSECS Pacific was "one of the most technologically advanced oceanographic expeditions ever carried out," according to Dr. Weiss. "The instrumentation and data processing techniques for the shipboard work were highly sophisticated."

Arnold E. Bainbridge, GEOSECS project director, explained that an on-board computer console utilized four electronic screens to display data telemetered from an underwater instrument package, or "rosette." Scientists at the console were thus able to study the distribution of temperature, salinity, oxygen, and light scattering, as well as a number of computed parameters such as water density, in real time.

Sampling was performed by two "rosettes," the lower of which housed the underwater sensors and telemetry equipment. Each "rosette" was equipped with 12 30-liter sampling bottles. As the "rosettes" were lowered and raised by cable, the scientists at the console could collect water at selected depths by the touch of a button.

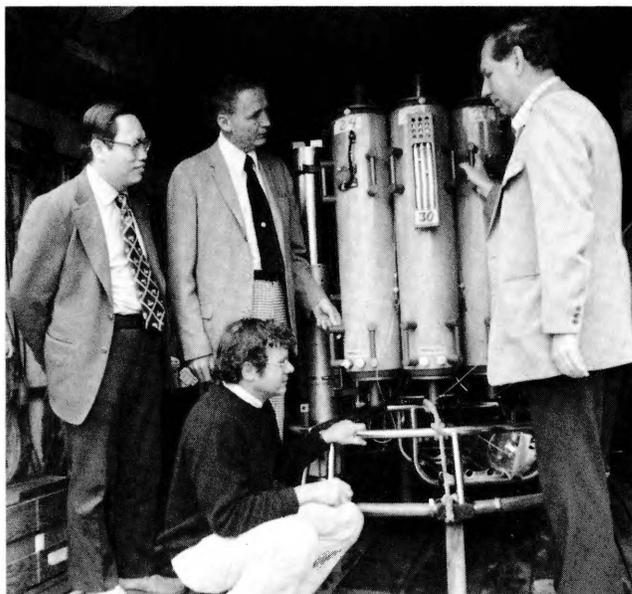
Two computers and automated equipment provided precise and rapid shipboard calculation of data, readying them for distribution to principal investigators two weeks after the conclusion of each leg of the expedition.

"It will be the end of 1976 before the water samples taken during the expedition will be analyzed," Dr. Weiss said. "Only then will we be able to accurately test many hypotheses regarding the circulation and mixing of deep-sea chemical and biological processes."

GEOSECS Pacific Chief Scientists

Chief scientists aboard *Melville* for the expedition were:

Leg I—San Diego-Honolulu: Dr. Harmon Craig; Leg II—Honolulu-Adak, Alaska: Dr. W. S. Broecker, Lamont-Doherty Geological Observatory, Columbia University, Palisades, N.Y.; Leg III—Adak-Tokyo, Japan: Dr. T. Takahashi, City University of New York; Leg IV—Tokyo-Honolulu: Dr. D. W. Spencer, Woods Hole Oceanographic Institution, Woods Hole, Mass.; Leg V—Honolulu-Pago Pago, Samoa: Dr. Ray Weiss; Leg VI—Pago Pago-Wellington, New Zealand: Dr. Pierre Biscaye, Lamont-Doherty; Leg VII—Wellington-Wellington: Dr. John Edmond, Massachusetts Institute of Technology, Cambridge, Mass.; Leg VIII—Wellington-Papeete, Tahiti: Dr. Craig; Leg IX—Papeete-Pa-



At top left, Dr. Harmon Craig, at right, and Feenan Jennings, of Washington, D.C., head of National Science Foundation's (NSF) International Decade of Ocean Exploration (IDOE), are surrounded by scores of the hundreds of containers of seawater taken aboard R/V *Melville* during GEOSECS Pacific cruise of 1973-74. Ship had just berthed at Nimitz Marine Facility after 35,000-mile, 10-month expedition. At top right, from left, Dr. Choo-Seng-Giam, chief of environmental quality program for IDOE; Jennings; Dr. W. S. Broecker (kneeling), of Lamont-Doherty Geological Observatory, Columbia University; and Arnold E. Bainbridge, GEOSECS project director, inspect one of two, underwater, electronic "packages" incorporating 12 30-liter sampling bottles used in making deep, in situ measurements and in collecting seawater for analysis in the ship's laboratories.

At lower left, Dr. Ray F. Weiss opens one of 12, stainless-steel, 280-liter (65-gallon) Gerard bottles used in collecting seawater during cruise. One of the two "packages" is shown, lower right, being retrieved during GEOSECS Atlantic operations in arctic waters by Scripps marine technicians Alan Osgood, Leonard Cunningham, and Bruce Waldorf, left to right, aboard R/V *Knorr*, based at Woods Hole Oceanographic Institution (WHOI), Woods Hole, Massachusetts.

GEOSECS (Geochemical Ocean Sections Study) has been described as man's most extensive chemical investigation of oceanic circulation and mixing processes, a program that is part of this nation's contribution to IDOE. GEOSECS Atlantic, the counterpart of GEOSECS Pacific, took place in 1972-73, out of WHOI. Drs. Craig and Broecker are members of the Executive Committee of the GEOSECS Scientific Advisory Council. Dr. Weiss is a member of the Advisory Council, as is Joseph L. Reid, also of Scripps.

Top left photo by George Smith, courtesy of San Diego Union; lower right photo courtesy of Woods Hole Oceanographic Institution.



peete: Dr. Peter Brewer, Woods Hole; and Leg X—Papeete-San Diego: Dr. Broecker.

Other cooperating institutions in the United States for both GEOSECS Pacific and Atlantic are the University of Miami, Oregon State University, Yale University, University of Rhode Island, University of Louisiana, University of Washington, University of Southern California, University of California at Los Angeles, University of Hawaii, and the U. S. Naval Oceanographic Office.

Foreign participation in the GEOSECS program includes West Germany, Japan, France, India, Italy, and Canada.

Tasaday Expedition

Laden with core samples that may hold the key to heavy metals buried beneath the sea floor off southeast Asia, R/V *Thomas Washington* returned to San Diego from the nine-and-one-half-month Tasaday Expedition on March 18, 1974.

Other scientific findings included the discovery of:

- a geologically young subduction (trench) zone east of Luzon in the Philippine Sea;
- a sea-floor spreading center in the Central Basin fault that lies in a line from Taiwan to Yap in the Philippine Sea;
- an exceptional ability to locate and devour food by certain groups of benthic (bottom) marine animals in a food-poor environment located at a depth of 6,000 m about 644 km north of Hawaii;
- an anomalously high rate of acoustical absorption in the Sulu Sea that appears to be inconsistent with other measurements made in the open ocean and adjusted for temperature variance.

A continuation of prior research in the Bay of Bengal (southeast of India) and in the Andaman Sea (south of Burma) confirmed previous speculation that thick sediment from the Bengal Fan, derived from continental India before its collision with southern Asia, is being scraped off the underthrusting sea floor and folded into the Indo-Burman ranges, the Andaman and Nicobar islands, and the islands off the coast of Sumatra.

Tasaday research consisted of a variety of biological, ecological, and geophysical investigations conducted by scientists from the United States and Japan on board the *Washington* during her 44,500-nautical-mile expedition to the western Pacific and eastern Indian oceans.

Robert C. Newbegin was cruise captain for the first five legs of Tasaday. John W. Bonham relieved Newbegin on October 7, 1973, and captained the 1,302-ton, 209-foot vessel for the remaining five legs.

Dr. Roger N. Anderson was cruise coordinator and chief scientist for one leg of the expedition. Other chief or co-chief scientists were Scripps's Drs. John R. Beers, Hugo F. Bezdek, John A. McGowan, Joseph R. Curry, David G. Moore (also of the Naval Undersea Center, San Diego), and Michael C. Gregg, and graduate students Peter Jumars and Eric Shulenberger; Cornell University's Dr. Daniel E. Karig; and the University of Washington's Dr. Bruce A. Taft.

Multidisciplinary Investigations

Tasaday's multidisciplinary oceanographic expedition, funded by the National Science Foundation and the Office of Naval Research, included water microstructure measurements off the California coast and in the central North Pacific Gyre (closed circulatory system); biology of the central North Pacific Gyre; physical oceanography of the Kuroshio Current off Japan; and geological and geophysical studies of the interarc basins of the western Pacific and the Bengal Fan in the eastern Indian Ocean.

From January 22 to February 17, 1974, the *Washington* was diverted from Tasaday for work with Scripps's FLIP (Floating Instrument Platform) on the North Pacific Experiment's (NORPAX) POLE project in the north central Pacific in a 320-square-km area near Hawaii. POLE was a field experiment devoted mainly to describing the intense winter-time interactions of the ocean and the atmosphere in enough detail to permit plans for later experiments with wide coverage of the ocean.

Tasaday Expedition was named for the Stone Age cave dwellers recently discovered in the Mindanao rain forest of the Philippines, said Dr. Anderson. "We had hoped that our expedition would be as successful in exploration and discovery in the oceans as the Tasadays were in escaping civilization for so many years. Although it will take time for all of the data to come in, preliminary results were gratifying."

Dr. Anderson conducted geophysical research in the Mariana Trough northwest of Guam. "Recovered cores are hoped to yield evidence of heavy metal deposits in that area," he said. "Our expectations are based on high heat flow and high sediment temperatures that suggest heavy metals may be leached from the rocks and precipitated in the sediments as seawater percolates through the rocks."

He said conditions of heavy sedimentation in the trough combined with the high temperatures may accelerate the "cooking" of sediment and eventually yield oil, adding, "That area can be compared to what the California borderland basins, such as the Santa Barbara Basin, may have been like 10 million years ago."

Studies by Dr. Karig included nearly continuous reflection, magnetic, and bathymetric profiling while en route from Yokohama to Singapore through the Philippine Sea. His research yielded two findings. Surveying, dredging, and coring east of Luzon substantiated that a geologically young subduction zone is developing along this margin. "We found a trench in the process of being formed, and also conducted a detailed survey of the Central Basin fault, which lies in a line from Taiwan to Yap, and determined that the fault is a spreading center," said Dr. Karig.

Dr. Karig's research also included work at three seismic refraction stations: one for a survey with the assistance of the R/V *Bosai Maru*, a Japanese vessel, in the Shikoku Basin to investigate non-uniform properties in the earth's mantle; the other two for one-ship sonobuoy profiles in the west Philippine Basin.

Dr. Bezdek's readings while measuring acoustic absorption in the Sulu Sea (between Sabah and the Philippines) were "anomalously high, and appear to be inconsistent with measurements made in the open ocean and adjusted for temperature variance," he said. "The reasons for this acoustic absorption inconsistency is a question that remains to be answered. Sometimes you get answers, and other times you get questions."

The Sulu Sea is a "closed system" having no interaction with adjacent water bodies, he said. The water temperature in this area is extremely warm (about 10.5°C) to a depth of 4 km as compared with an open-ocean temperature average (about 1.5°C).

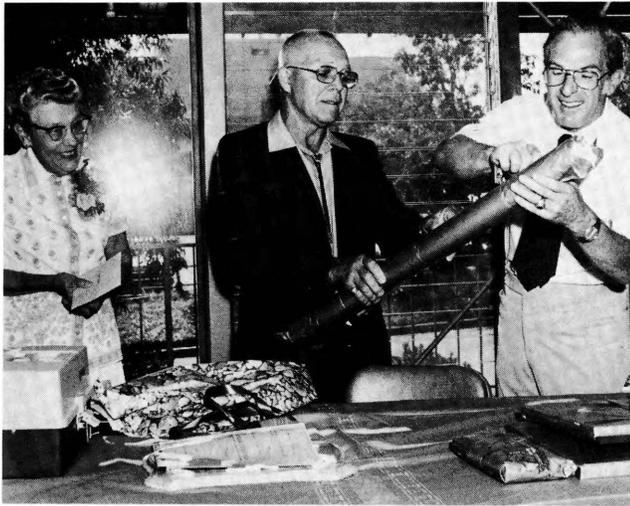
Previous geophysical work in the Bay of Bengal by Drs. Curry and Moore had shown that the sediment column exceeds 16 km in thickness at the northern end of the Bay, one of the thickest sediment sections in the world. During Tasaday, work was continued farther to the southwest in the Bay of Bengal to delineate thicker parts of the sediment column for the purpose of relating to geological history. Much of that sediment was derived from continental India prior to its collision with southern Asia in early Tertiary time (about 55 million years ago). Drs. Curry and Moore investigated these regions of deformed sediment to attempt to evaluate the process of the scraping of a thick column of sediment from a subducting or downgoing plate, and the thrusting and uplifting into a mountain range.

Kuroshio Current Research

Under the direction of Dr. Taft, the flow of the Kuroshio Current over the Izu-Ogasawara Ridge was studied by means of free-vehicle current meters, expendable bathythermographs (XBT), STDs (salinity-temperature-depth-measuring devices) and drogues.

The Ridge presents a major topographic obstacle to the flow of the Kuroshio, and by tracking selected isotherms (a line on a map connecting points having the same temperature at a given time) the current's path over the Ridge can be determined. The main focus of the work was on the interaction of the deep flow of the Kuroshio with the Ridge. During the work the position of the surface Kuroshio was monitored by means of XBT drops. The density field in the vicinity of the Ridge was determined from STD observations and will be used to compute the geostrophic (deflective force due to the rotation of the earth) flow field. Drogue measurements gave an indication of the surface current distribution and the relationship between the current and subsurface temperature distribution. On 15 stations concentrations of phosphate, silicate, and oxygen were determined and will be used to trace the pattern of the deep flow through the Ridge and around it.

Two legs of Tasaday had as their dual purpose the investigation of the temperature and salinity microstructure of the water column, and study of the various aspects of the biological energy flow, nutrient cycling, and plankton in the central gyral region of the North Pacific, although considerable work was also accomplished at the western edge of the California Current.



With Mrs. Noel L. Ferris watching, Peter Branson, marine operations manager, at right, helps Captain Ferris unwrap fishing rod during retirement luncheon for the veteran Scripps skipper, who served 16 years with the fleet. Luncheon was held at Nimitz Marine Facility.

Drs. Beers and McGowan of the Institute of Marine Resource's Food Chain Research Group and Scripps's Marine Life Research Group, respectively, conducted studies on the plankton food-chain dynamics in the central gyral region of the North Pacific, an area Dr. Beers said has "a relatively orderly and predictable plankton population structure. Principles that result from the quantitative description of the pelagic ecosystem in an orderly environment such as the gyre will be important aids in developing an understanding of highly complex and less predictable systems such as found, for example, in the California Current."

Seasonal Comparisons Recorded

Dr. Beers's work was done in June and July, and Dr. McGowan's investigations were in February and March for seasonal comparison. These were parts of an extensive program that includes several earlier cruises to the gyral region.

In addition to a basic set of measurements and sample collections that will provide information on seasonal and annual differences, a variety of special biological studies were conducted, including the use of free-vehicle traps to obtain abyssal (deep-water) amphipods (a type of crustacean), the rearing of predaceous copepods for the purpose of determining their life cycle, the study of micro-zooplankton populations in waters below the depth to which light sufficient for algal plankton production penetrates, and studies of nekton.

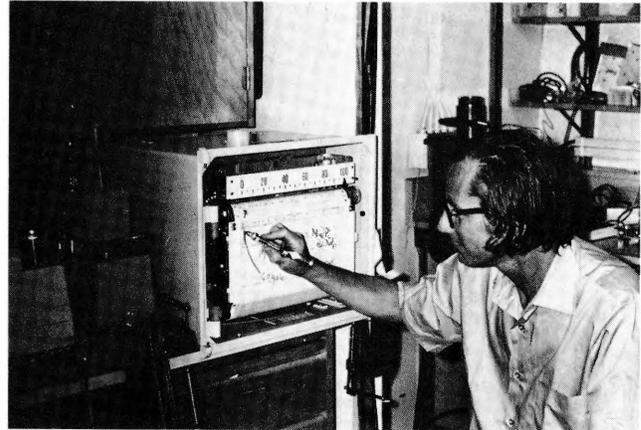
Dr. Gregg directed investigation of the temperature and salinity microstructure of the water column. Observations emphasized the comparison of the yearly changes in the heat content of the upper 1 m of water to the centimeter-scale temperature fluctuations from data records.

He said that an understanding of the physical mixing processes on these small scales is necessary before oceanographers can fully detail the heat and salt budgets of the oceans. "Such information can, in turn, be used to predict the dispersal of pollutants introduced into the oceans," he said.

Two Scripps graduate students were chief scientists during the expedition. Shulenberg's work was an extension and broadening of the ongoing Central Gyre biological studies being conducted by Dr. McGowan's group. His work was focused on the eastern half of the northern gyre to help elucidate whether the gyre is indeed one coherent community of marine organisms, or perhaps two subtly different communities.

Jumars coordinated continuing investigations by Dr. Robert R. Hessler of the deep-sea-bottom community structure in unproductive regions of the Central Gyre. About 640 km north of Hawaii, Jumars reported, "With the aid of baited traps, we found that in that food-poor environment, where most animals are less than a centimeter long, a

number of very large animals, especially fish, and a group closely related to sand fleas, had exceptional ability in the locating and devouring of food."



Paul Dreizen, M.D., Dean of the State University of New York Downstate Medical Center, Brooklyn, at work aboard R/V Alpha Helix off the Kona Coast of Hawaii. His studies were concerned with the effects of pressure and temperature on the structural-functional relationships of muscle proteins in benthic fishes.

Walter Schneider

THE GRADUATE DEPARTMENT

Graduate education is administered through the Department of the Scripps Institution of Oceanography. Within this Department, curricular programs are offered in applied ocean sciences, biological oceanography, geophysics, marine biology, marine chemistry, geological sciences, and physical oceanography. Each curricular group has its own special requirements for admission (in addition to those applying to the Department as a whole) and its own course requirements and policies.

In the rapid evolution of modern oceanography, growth is often most vigorous at the boundaries of established disciplines, so that the interests of a given student may fall somewhere between the limits of two curricular programs. It is the intent of Scripps's graduate program to provide the maximum flexibility in meeting the specific interests of individual students.

The Department was chaired by Dr. Joseph R. Curry, professor of marine geology. Dr. Michael M. Mullin, associate professor of oceanography, served as vice-chairman.

GRADUATE CURRICULAR PROGRAM. A brief description of the seven curricular programs, whose 59 faculty members also serve in various research divisions, laboratories, and research groups, follows:

Applied Ocean Sciences (Dr. Victor C. Anderson). 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; namely, Aerospace and Mechanical Engineering Sciences and Applied Physics and Information Science. An attempt will be made to produce modern engineers with a substantial training in oceanography and oceanographers with a significant ability in modern engineering. Instruction and research are not restricted to structural, mechanical, material, electrical, and physiological problems operating within the ocean, for they include 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.



Valerie Loeb, graduate student in biological oceanography, repairs an Isaacs-Kidd plankton trawl net on the fantail of the Thomas Washington during *Tasaday XI*.

Dr. Elizabeth Venrick

Biological Oceanography (Dr. James T. Enright). Biological oceanographers are concerned with the interactions of populations of marine organisms with one another and with their physical-chemical environment. Research 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, and fisheries biology; taxonomy and zoogeography of oceanic organisms; and behavior as it affects distribution and sampling problems. The curriculum is designed to prepare students for original research and teaching in this interdisciplinary field.

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 which take place within it.

Marine Biology (Dr. Ralph A. Lewin). This curriculum is concerned with the study of the development, adaptation, and function of organisms in the marine environment. The comparative physiology, biochemistry, and developmental biology of marine organisms are stressed in course work of the curriculum. Students specializing in subjects from neurophysiology to barobiology will find breadth of interest and intensity and sophistication of the experimental approach as adapted to conventional marine technology.

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 interactions 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. James W. Hawkins). This curriculum emphasizes the application of observational, experimental, and theoretical methods of the basic sciences to the understanding of the solid earth,

ocean, atmosphere, and the solar system. Principal subprograms at Scripps are marine geology, petrology, and geochemistry. Expedition work at sea and field work on land are emphasized as an essential complement to laboratory and theoretical studies. Marine geology is the field of study concerned with the origin, properties, and history of ocean basins and with the geological processes that affect them. Petrology is the study of the origin and history of the rock complexes of the earth's crust and upper mantle, with emphasis on the igneous, metamorphic, and sedimentary rocks of the oceanic island, abyssal plains, and deep-sea trenches; the study of characteristics and interrelations of the oceanic and continental crust; and studies of lunar and meteoritic materials. The geochemistry program is designed for students with undergraduate majors in either geology or chemistry. Areas of advanced study and research include the geochemistry of the ocean, the atmosphere, and the solid earth; nuclear geochemistry; studies of volcanic and geothermal phenomena; the interaction of sediments with seawater and interstitial waters; geochemical cycles; and the history and composition of the ocean and sedimentary rocks.

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; and the properties and propagation of ocean waves.

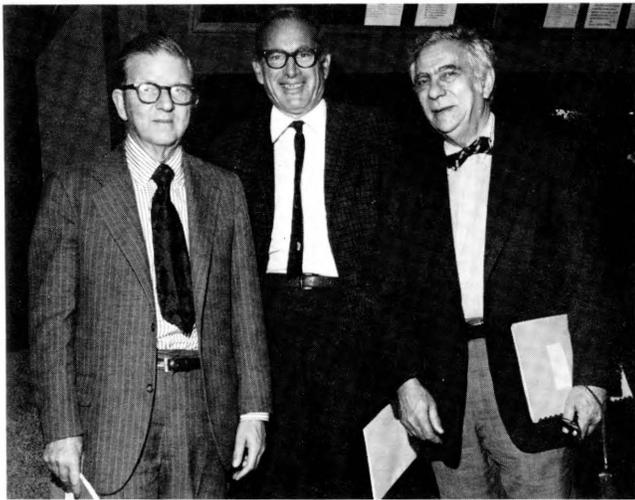
GRADUATE STUDENTS AND DEGREE RECIPIENTS. In the fall of 1973, 31 new students were admitted to graduate study. Of these, 4 were in marine biology, 5 in geological sciences, 4 in marine chemistry, 5 in biological oceanography, 4 in physical oceanography, 5 in geophysics, and 4 in applied ocean sciences. Fifteen were California residents, 12 were from out of state, and 4 were from foreign countries. Enrollment at the start of the 1973 school year totaled 180 students.

During the Academic Year 1973-74, 11 Master of Science degrees and ten Doctor of Philosophy degrees were awarded by UCSD to students having completed advanced studies at Scripps. The names of degree recipients and the titles of doctoral dissertations are listed in Appendix E.



Director Nierenberg, right, chats on Scripps Pier with four students who were recipients of grants from a philanthropic organization in Los Angeles, Achievement Rewards for College Scientists. From left, Gary H. Dobbs, III; Thomas W. Okita, and Yolanda Montejano, marine biology; and Brock Bernstein, biological oceanography.

Glasheen Graphics



UC President Charles J. Hitch, left, and Emanuel Piore, right, board members of Resources for the Future, Inc. (RFF), photographed with Director Nierenberg during visit of organization's officers and board members to the campus. RFF, an independent social science research and grant-making organization, has analyzed land use, pollution control, the economic and political mechanisms for managing the environment more effectively, and the supply and demand of natural resources.

RESEARCH ACTIVITIES

Advanced Ocean Engineering Laboratory

Now into its sixth year of operations, the Advanced Ocean Engineering Laboratory (AOEL) has been undertaking investigations into diverse areas of advanced marine technology and physics. These research efforts have been supported by the Advanced Research Projects Agency (ARPA) under contract with the Office of Naval Research (ONR), although recently ONR has contributed funds in specified areas. During the year, six projects were supported by AOEL, with all but the following two being described in other sections of this annual report.

Stable Floating Platform Program—Dr. Fred N. Spiess.

Studies of an eighth-scale, large, floating-platform module were conducted in the open sea on two occasions. Coupling the deployable legs from a flippable barge formed a rigid model of a 107-m triangular component from which an open-ocean platform could be assembled at a remote location. Force, motion, and wave data were recorded and analyzed, and comparisons with both 1/100th-scale and theoretical studies were surprisingly good.

The flippable barge component of this system was later evaluated as an ocean engineering work platform, and it showed excellent promise for salvage, ocean mining, submersible tending, and other underwater tasks.

Radio Scatter Group—Dr. Robert H. Stewart and Joseph W. Joy.

This group is continuing to use radio scatter from the sea to measure oceanographic processes remotely. Data recorded at Wake Island have produced the first, very-high resolution, directional distribution of ocean-wave energy. Seven-second ocean waves were measured with an azimuthal resolution of $\pm 3^\circ$. In another experiment, measurements made at San Clemente Island, off California, indicate radio scatter can be used to measure ocean surface currents out to 100 km from land with

good accuracy. This year the group is working with NORPAX (North Pacific Experiment), Stanford University, and the Stanford Research Institute to evaluate methods of using radio waves propagated via an ionospheric path to measure ocean surface winds out to 3,000 km from land.

James Cairns, Gordon Williams, and Drs. Walter H. Munk and Frank E. Snodgrass have been investigating internal waves and, in addition to Drs. Charles S. Cox and Michael C. Gregg's research, have been examining various aspects of ocean microstructure. These studies are mentioned in sections under the Institute of Geophysics and Planetary Physics and Ocean Research Division in this report.

Dr. William G. Van Dorn's research on breaking waves and the experimental work on the air/sea interface, by Drs. Carl H. Gibson, Carl A. Friehe, and Frank H. Champagne, are described in the Ocean Research Division section of this report.

Deep Sea Drilling Project

The Deep Sea Drilling Project (DSDP) is a scientific program whose objective is the exploration of the earth's crust beneath the oceans. The strategy is to drill holes and obtain core samples of the sediments and rocks beneath the seabed at locations throughout the world. This is done by using the dynamically positioned drilling ship *Glomar Challenger*, the only research drilling ship to sample the ocean bottom successfully in almost 6,535 m of water.

Begun in August, 1968, DSDP is supported by the National Science Foundation (NSF) through a contract with the University of California. Scripps Institution has been designated by the University to manage the project. DSDP is part of the NSF's Ocean Sediment Coring Program.

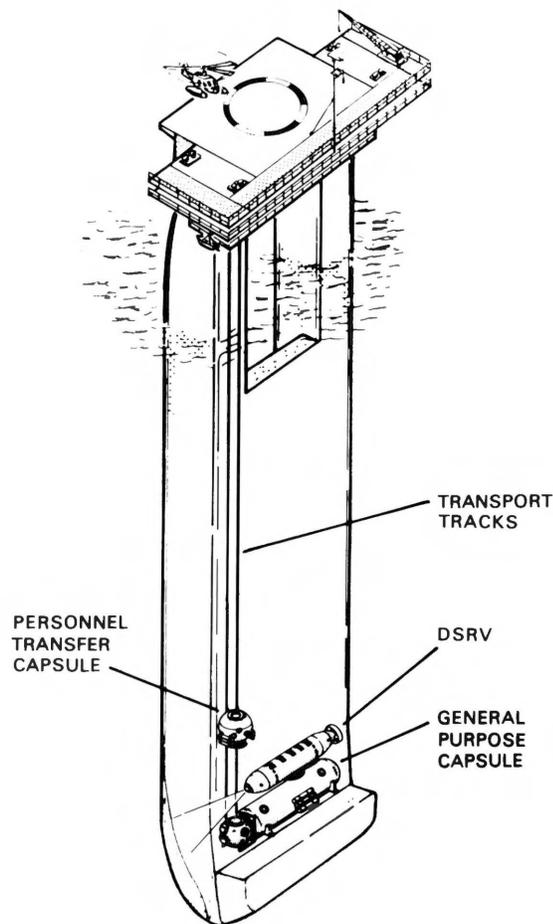
During Fiscal 1974, the center of Deep Sea Drilling Project operations shifted from the Indian to the Pacific Ocean. Significant and sometimes surprising evidence was recovered by scientists aboard the *Glomar Challenger* during the 23,000 nautical miles the ship traveled in this period. Technical progress was highlighted by the completion and installation of a new shipboard system called heave compensation (see chart). Two foreign nations formally joined DSDP with strong signals from others that they will shortly follow.

In February, 1974, a formal Memorandum of Understanding was signed by representatives of the USSR and the National Science Found-



Studies by the Advanced Ocean Engineering Laboratory into development of large, stable-floating platforms using flippable barges culminated in eighth-scale model tests in the ocean. Here, with its legs deployed, the model represents a 107-m, triangular, rigid module that could be a component of a much larger platform having possible floating airfield or power-plant applications. It could also be utilized for deploying a variety of other hardware for submarine research and support, deep-sea mining, long-term ocean research programs, and difficult salvage operations.

Advanced Ocean Engineering Laboratory



Artist's sketch of a flippable barge developed by Advanced Ocean Engineering Laboratory. Barge is adaptation of a design used for R/P FLIP, an engineering concept developed by Marine Physical Laboratory under direction of Dr. Fred N. Spiess, who also headed flippable-barge project.

dation, culminating negotiations that had been ongoing for nearly two years and which, at one point or another, had involved the highest levels of both governments. The Russians have agreed to contribute a substantial annual sum to the project for a period of five years; this is significant from both the economic standpoint, and in terms of scientific recognition. In the spring of 1974, the pace of negotiations with the Federal Republic of Germany increased rapidly; the result of continued, important discussion was the signing of a Memorandum of Agreement by representatives of the Federal Republic of Germany and Dr. Guyford Stever, director of the U. S. NSF, in Bonn, Germany, in July, 1974. The German agreement is very similar to that signed with the Russians, and also is effective from January, 1974. Both countries are developing significant programs for study of DSDP core material. In addition, both countries have had significant scientific representation on the drilling vessel in the past, and this formal recognition of cooperation and joint participation is particularly rewarding to all concerned.

In this same area of endeavor, important progress has been made with respect to the formal participation in DSDP, possibly within the near future, by France, England, Japan, and Norway.

In the main arena of its existence, DSDP recorded some impressive achievements. During Leg 32, for example, evidence obtained by the scientific team has contributed important new information concerning the South Atlantic Ocean. Curiously, the evidence was recovered during drilling operations in the northwest Pacific, which is an indication of the global nature of marine geology and geology in general at the present time. The same team gathered evidence leading to the early con-

clusion that during a period of earth history, ranging from 115 to 160 million years ago, there was an apparent worldwide doubling of the rate at which the new oceanic crust was formed by the process commonly known as sea-floor spreading.

When the *Challenger* sailed from Hakodate, Japan, in mid-August, 1973, scientists were prepared to search the layers of sediment on the ocean floor for clues about the earth's geography and environment during the late Mesozoic Era, an interesting time in the world history that lasted from 65 to 160 million years.

Geophysical surveys, dredging, and coring give clues that the region between Japan and the central Pacific is the largest remaining area of the ocean floor older than 110 million years. The earth's rocky crust under the ocean is slowly but constantly being formed and spreading away from the mid-ocean ridges while older areas of crust are slowly sinking into the trenches. This process proceeds at such a rate that only a few ancient places are left in the oceans in which to explore for the story written by deep-sea life of their habitat, or to study areas that have a magnetic record of the underlying crust from which the positions of ancient continents and ocean basins can be calculated.

During Leg 32, a number of holes were drilled that established the identity and geologic age of several groups of magnetic bands in the western Pacific Ocean. One of the most significant results established that a characteristic magnetic banding in the northwest Pacific corresponds to banding existing on both sides of the Atlantic Ocean. This banding represents the period ranging from approximately 115 to 150 million years ago; its width indicates that the sea floor spread at about twice the normal rate during that period.

This evidence, then, also shows that the opening of the South Atlantic Ocean Basin can be dated, with new-found accuracy, to about 125 to 130 million years ago. At that time, the newly formed Atlantic Ocean must have looked very much like a long Red Sea or Gulf of California of today, a mere notch in a major continent.

During *Challenger's* port call at Honolulu in October, 1973, a heave-compensation system, created to improve core samples and prolong bit life, was installed on the ship. In succeeding months, the system was exposed to long and intensive testing under a variety of sea and weather conditions. This marks the first active heave-compensation system that has ever been used on a drill ship. Several inconsistencies and technical "bugs" required extended effort to work out, but thanks to the wholehearted cooperation and effort of Global Marine Inc., of Los Angeles, from whom DSDP leases the drilling research vessel *Glomar Challenger*, these difficulties were overcome. In early July, 1974, DSDP accepted the heave-compensation capability that is now an integral part of the ship and drill function.

Following its Honolulu port call, *Challenger* embarked on Leg 33 to investigate the idea of a "hot spot" origin of linear island chains in the Pacific. The term "hot spot" refers to the suggestion that some sort of melting anomalies exist in the earth's mantle over which active volcanic islands are formed.

Investigating the Hawaiian Islands, J. D. Dana, on the American Exploring Expedition of 1849, noted the difference between what are now called linear island chains, that stretch across the central and northern Pacific, and "island arcs," or curved chains of islands, that occur at the western borders of the Pacific Ocean near the continent of Asia. Much more recently, it has been proposed that linear island chains are formed by the movement, in this case, of the entire Pacific Plate over more or less fixed "hot spots." As the Plate drifts away, old volcanoes move with it and new ones form over the "hot spots." In this model, a chain of volcanic islands would eventually result in a manner very like charred holes in a piece of paper passed over a candle flame. It has also been proposed that the Pacific Plate moved relatively northward prior to 42 million years ago, and formed the Emperor Seamount chain, the Line Islands, and the Ellice, Gilbert, and Marshall chains. It is thought that at about 42 million years ago the movement of the Plate changed direction, forming elbows in these three chains and subsequently creating the Hawaiian, Tuamotu, and Austral chains, respectively. If the "hot spots" (or perhaps more properly called melting anomalies) are indeed relatively fixed to some inner portion of the earth, and have been so over the last 70 million years, then a sense of absolute motion directions of all of the plates in the world could be determined.

The Line Island chain was chosen for the test sites because holes could be drilled near atolls and thus record the history of coral reefs among the island chain as well as to study its volcanic history. Data



Dots on map indicate sites at which the Deep Sea Drilling Project has drilled since project began in August, 1968.

Deep Sea Drilling Project

from two sites drilled near Fanning and Christmas islands, at the center and southern end of the chain, respectively, combined with data from a site near the northern end of the island chain drilled on an earlier DSDP leg, show that the fixed "hot spot" theory does not explain the evidence, at least for the Line Island chain.

The geological history of all three sites is virtually identical. Volcanism ceased at or near each site between 80 and 85 million years ago, in the Cretaceous period; reefs flourished nearby in Cretaceous time and some of them have continued to the present day. Those parts of the volcanic islands, undersea ridges, and seamounts, upon which the corals grew, developed into the present atolls of the chain.

A third site to test the "hot spot" hypothesis was drilled at the north end of the Tuamotu chain. Additionally, Leg 33 scientists examined the theory that this atoll-capped ridge was formed during a shift in the direction of movement of the Pacific Plate over the same "hot spot" that had earlier created the Line Islands. This shift in direction of movement had also been proposed to have formed the bend in the Hawaiian Island-Emperor Seamount chain northwest of Midway Island.

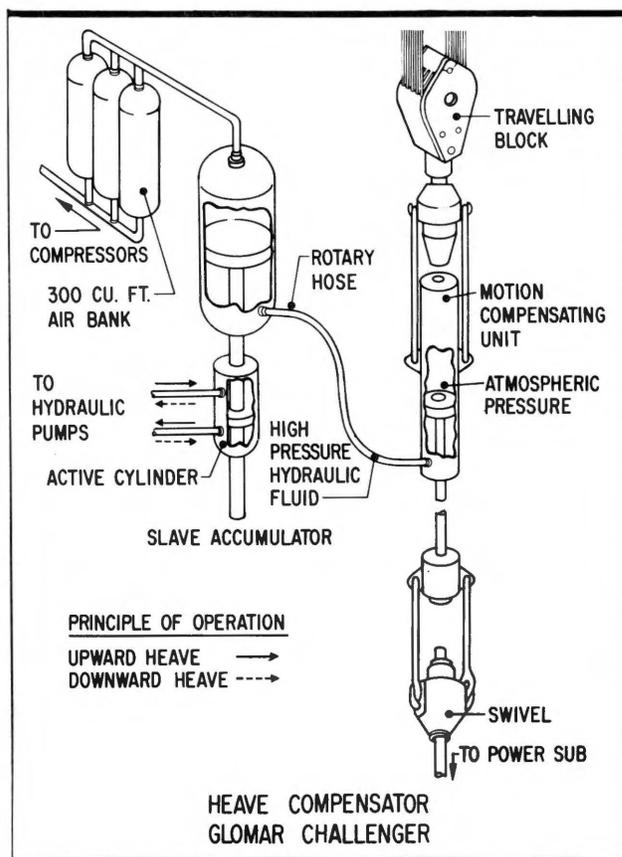
Results from the Tuamotu Ridge site indicate a minimum age of the cessation of volcanism at 29 to 50 million years ago, whereas the bend in the Hawaiian-Emperor chain had been estimated as having occurred between 42 to 48 million years ago. Thus, it would appear that the ages of the Tuamotu edifices are somewhat older than those at an apparent equivalent point in the Hawaiian-Emperor chain. Sediments recovered from the hole show that reefs flourished in the region at least 50 million years ago, after volcanism stopped. Several subsequent periods of reef erosion are evidenced by beds of shallow-water fossils such as corals, mollusks, and bryozoans, which were found in the deep-water basin drilled by the DSDP scientists.

In a summary written shortly after Leg 33 ended (in Papeete, Tahiti, in December, 1973), the co-chief scientists noted that (1) no "hot spot" hypothesis that requires systematic movement of the Pacific Plate over a melting anomaly beneath it can account for the geochronology of Line Island volcanism, and (2) it is apparent that these islands and seamounts were formed by a mechanism different from that postulated to explain the volcanic history of the Hawaiian-Emperor chain.

Coupled with the results derived from previous DSDP legs, the findings on Leg 33, while negative in nature, tend to establish a firm basis for more exact investigations in the future.

With the onset of Leg 36, the continuing story of DSDP moved again into the Atlantic Ocean, but the route took the *Challenger* through a desolate and forbidding corner of the world. The ship departed Ushuaia, Argentina, on April 4 and arrived in Rio de Janeiro, Brazil, on May 22, after drilling and coring in the southernmost Atlantic Ocean, Scotia Sea, and the turbulent Drake Passage. The work was accomplished in an area having a reputation for high winds and seas that dates back to the earliest voyages of discovery.

The sites for Leg 36 were originally selected to study the complex



Deep Sea Drilling Project technical progress was highlighted during year by successful development and utilization aboard D/V Glomar Challenger of heave-compensation system, as indicated in schematic drawing.

Deep Sea Drilling Project



D/V Glomar Challenger encountered stormy weather and ice floes in Antarctic Ocean operations.

Deep Sea Drilling Project

geologic history of the Scotia arc, which joins South America to the Antarctic Peninsula; the submarine plateau on which the Falkland Islands are situated, and the southernmost part of the Atlantic Ocean Basin. This region has an important bearing on the origin and development of volcanic island arcs and deep-sea trenches. Also, the circulation system of the world's oceans, a major climatic influence both in the past and present, is to a considerable extent controlled by the geology of the southernmost Atlantic, Scotia Sea, and Drake Passage regions.

Constraints imposed by long-term planning for DSDP and equipment problems on preceding cruises dictated a sailing date for Leg 36 that was somewhat late in the season for work in the Antarctic Ocean. The stormy weather encountered in the Drake Passage south of Cape Horn was primarily responsible for the loss of 3,800 m of drill string at the first site. Continuing high winds and heavy seas made operation in the iceberg-infested waters of the Scotia Sea hazardous. The drilling program was modified, therefore, to concentrate on problems of the initial opening of the South Atlantic Ocean by the rifting apart of South America and Africa and of the history of oceanic circulation.

Ten holes were drilled at six sites, although penetration at two sites in the Drake Passage and the Argentine Basin was limited by bad weather. Data from four other sites, however—three on the submerged platform east of the Falkland Islands and one in the deep Atlantic between this platform and Africa—constitute a major contribution to man's knowledge of the ancient southern supercontinent of Gondwanaland, the evolution of the southern Atlantic Basin, and the history of oceanic circulation.

Ten specific scientific conclusions resulted from work done on Leg 36:

1. Submerged continental crust, once part of the ancient southern supercontinent of Gondwanaland, exists in the South Atlantic Ocean up to 1,400 km east of the South American mainland and 800 km east of the Falkland Islands. The eastern part of the submerged platform on which the islands are located is composed of a Mesozoic sedimentary cover overlying this continental basement. Before the opening of the South Atlantic 130 million years ago, the platform was situated southeast of the Cape of Good Hope and was contiguous with Antarctica as well as South America and Africa.

2. The continental rocks underlying the Falkland Plateau are probably well over 600 million years old and very likely the oldest rocks recovered so far in the course of DSDP.

3. The weathered top of the continental rocks was thought by the scientists on the ship to indicate a Mediterranean climate in the region during the Jurassic period (150 million years ago) between the two glacial epochs that occurred 250 million years ago and again within the last 25 million years in the same region.

4. The Jurassic deposits overlying the basement are probably the oldest sediment coring done during DSDP. They reflect the first transgression of the sea over the platform.

5. A major break in the fossil record may reflect updoming of South America and Africa prior to their fragmentation.

6. Conditions of poor circulation and poor oxidation early in the history of the Atlantic Ocean Basin resulted in the decay of organic debris to produce oil shale.

7. An open aerated marine environment developed in the mid-Cretaceous (100 million years ago), probably when the submerged platform finally separated from Africa.

8. The platform subsided effectively to its present depth by the late Cretaceous (80 million years ago).

9. Climatic deterioration—cooling—is apparent by the Paleocene (60 million years ago), and cold Antarctic water invaded the area by Oligocene (40 million years ago). Evidence of icebergs was present for the past 10 to 12 million years.

10. Oceanic bottom currents, similar to those of today, have been depositing and eroding material in the South Atlantic since the late Cretaceous (70 million years ago). Fossils in the Argentine Basin up to 28°S include forms that lived in the Antarctic and were transported north by bottom waters.

In June, Leg 37 began what is the most ambitious engineering effort in the history of the project. Coupled with the important scientific prospects involved, the entire team aboard *Challenger* wrote a significant chapter in the geological research of the Earth. The goal was to drill deeper into Earth's Layer 2 than had ever been done before, an achievement that will have far-reaching effects not only on present DSDP operations but on the proposed International Phase of Ocean

Drilling scheduled to begin in August, 1975.

Leg 37 accomplished its goal. In July, 1974, the team was able to penetrate 582 m into Layer 2. Knowledge of Layer 2 is of particular importance to future planned work in deep-sea drilling, which includes major efforts in preparing for extensive penetrations into both Layer 2 and Layer 3 of the oceanic crust.

Geological Research Division

The research group of Dr. Gustaf Arrhenius, including Dr. Saara K. Asunmaa, Mary Fisk, R. W. Fitzgerald, Jane Z. Frazer, Hitoshi Fujita, graduate student Jimmy Greenslate, and Donna L. Hawkins, has devoted work to 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. Besides their general scientific interest, 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, Greenslate has for the first time clearly documented the active role of the microfauna in building up the surface layers of manganese nodules by constructing tubes, domes and other shelter structures from microscopic mineral grains, including a large proportion of iron- and manganese-oxyhydroxide minerals. In this respect the manganese nodules provide an analog to coral reef structures but in a different regime of the ocean and involving oxides rather than carbonates.



Participating in a ceremony acknowledging the gift of a digital seismic recording system from Mobil Oil Corporation to the Institution were Louis Casteel, at left, general manager of Mobil's Exploration Service Center, Dallas, and Associate Director George G. Shor, Jr. System was to be installed aboard R/V Thomas Washington for studying sedimentary layers under Pacific Ocean.

Greenslate has also demonstrated that ferromanganese concretions begin growing largely within the cavities formed by the skeletons of unicellular organisms, such as diatoms, and gradually transgress the confines of these walled structures. The incipient nodules may grow either inorganically or by mediation of microorganisms, such as bacteria; the bacteriological aspects of this question are being pursued by Dr. Kenneth H. Neelson. This embryonic state of nodule growth is characterized by an exceptionally low iron content in the manganese oxyhydroxide minerals (less than 2 percent FeOOH). These studies have all been carried out on material from the equatorial Pacific region.

Electron diffraction techniques have been used in an attempt to resolve the crystal structure of individual crystallites and crystal aggregates contributing to these formations.

Under Fitzgerald's guidance and with important contributions from Dr. Fujita, the instrumental facilities have been further developed to suit the particular needs for high-resolution analysis of composition and structure of solids. Fitzgerald, Dr. Fujita, and Frazer, in collaboration with Ron La Borde, have also extensively contributed to the further development of the Scripps Analytical Facility. The most important development here during the past year has been the addition to the scanning electron microscope facility of a novel-type, X-ray detection and display system (Ortec Delphi). This system incorporates an on-line computer that makes it possible to carry out real-time chemical analysis in microscopic domains. This acquisition has been made possible by developmental collaboration with the manufacturer.

The high-speed, X-ray, spectrometry system constructed earlier by this group has been further elaborated by Greenslate, Fitzgerald and Dr. Fujita, and has been tied in to a new on-line computer facility intended as a central computer for data processing within the entire analytical facility. The initial programming efforts on this system are being carried out by Frazer.

The Scripps Sediment Data Bank directed by Frazer, assisted by Hawkins and Fisk, has added about 2,700 sediment descriptions and more than 500 manganese nodule analyses during the past year, mainly from the Indo-Pacific area; the total number of data points in the bank exceeds 43,000. Demand for output from Scripps students and staff, as well as from industrial and governmental sources, has been increasing, and the interest in use of the data output has stimulated substantial con-

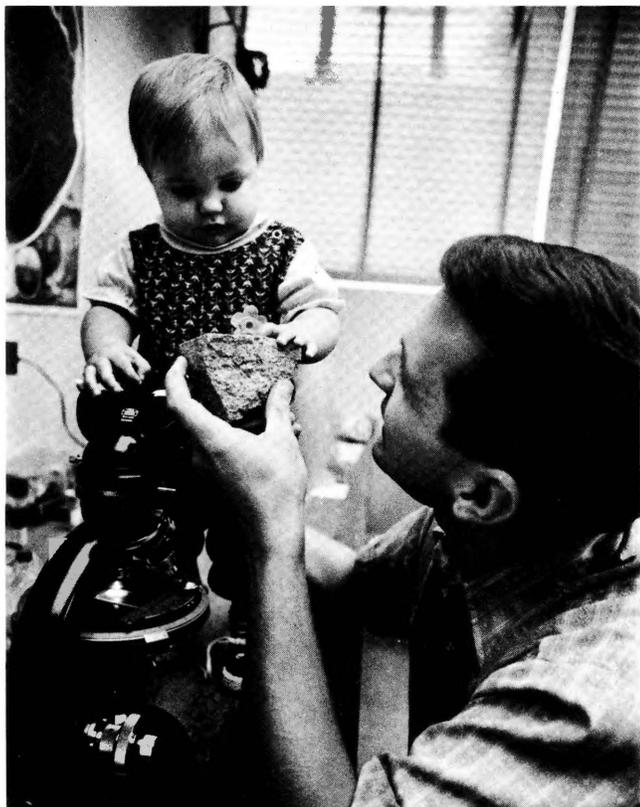
tributions from the German Government-Industry Collaborative Program for Ocean Technology and from the University Research Foundation. Present work on the Sediment Data Bank involves expanding the system to include analytical data on ocean sediments and to make data accessible from interactive remote terminals.

Drs. Asunmaa and John F. Asmus have participated in the program initiated by Dr. Walter H. Munk for Science in the Arts by studies of the microstructure of 18th-century textiles.

With La Borde, the group initiated a number of informal teaching programs and participated in formal courses at the graduate and undergraduate levels, teaching students from Scripps and other UCSD departments to apply available techniques to actual problem solving.

In collaboration with Frances L. Parker and graduate students Charles G. Adelseck and Thomas C. Johnson, Drs. Wolfgang H. Berger and Peter H. Roth continued their studies on the preservation of microfossils and nannofossils in deep-sea sediments. The problem of whether planktonic foraminifera and associated microfossils dissolve during settling or on the sea floor was investigated in the eastern tropical Pacific Ocean, by net towing at great depths and by box-core sampling. The tow samples demonstrate that little or no dissolution takes place during descent for particles of sand size, except for the finest sizes, at abyssal depths. Box cores recovered assemblages of calcareous foraminifera at the sediment-water interface well below the regional calcite compensation depth. The dissolution of coccoliths on the sea floor was investigated in a broad survey covering the South Pacific. A coccolith lysocline (unlike a foram lysocline) is difficult to define, but can be recognized near 4,000 m depth as a considerable drop in diversity of assemblages. A comparison of dissolution aspects of coccoliths and forams shows that coccolith assemblages are good indicators of dissolution above the lysocline, while forams are more sensitive below the lysocline. An initial study of dissolution of siliceous microfossils (Johnson) established a dissolution ranking and the fact that preservation is correlated with fertility (through production) and topography (through resedimentation).

Work on plate stratigraphic problems by Drs. Berger, Edward L. Winterer, and Jerry L. Matthews continued. The aim is to show how fertility and dissolution patterns combine with plate motions to produce stacks of sediments with characteristic properties. The inter-



Eight-month-old Andrea Divis examines a 2.5-billion-year-old sample of granitic gneiss held by her father, Allan F. Divis, a graduate student in geological sciences. Sample is from Mexico's Sierra Madre. Divis is studying causes of what he describes as an 800-million-year "dead spot" in geologic growth of the Sierra Madre and other geologically similar land areas in Australia, South America, and Africa.

Had Andrea looked through her father's petrographic microscope, she would have seen the magnification (at right), from an actual diameter of 4 mm of a 1.7-billion-year-old sample of gneiss from the Sierra Madre. Photograph was taken with a photomicrograph attachment on the petrographic microscope.

Photo at left by George Smith, courtesy of San Diego Union; at right by Allan F. Divis

pretation of acoustic profiler records of deep-sea sediments hinges on a proper understanding of these various factors, as well as diagenetic processes.

Dr. Harmon Craig's group was primarily occupied with GEOSECS Pacific expedition work during 1973-1974. Dr. Craig was expedition coordinator for the Pacific work and served as chief scientist on R/V *Melville* for Pacific Legs 1 and 8. In June, he gave a series of lectures at the Batsheva Summer School in Israel, after which he and Valerie Craig carried out field and museum work in Greece, continuing their study of the provenance of classical Greek marbles.

A major advance in the study of the excess helium-3 anomaly in deep-ocean water was made during the year. The new He³/He⁴ ratio mass spectrometer was put into operation, and Dr. John E. Lupton and Dr. Craig studied the helium isotope ratio in helium trapped in the glassy rims of submarine tholeiite-basalt pillow flows. Measurements of helium in basalts from the East Pacific Rise, both north and south of the triple junction of the Pacific, Cocos, and Nazca plates, and in the Lau Basin in the western Pacific, showed that the He³/He⁴ ratio in the chilled glass is 10 times the atmospheric ratio, while the He³/Ne ratio is 1000 times atmospheric. The He³/He⁴ ratio in the glass is the same as the ratio in the "excess helium" in deep water over the crest of the East Pacific Rise, where He³ is as much as 50 percent supersaturated relative to solubility equilibrium with the atmosphere. These results provide a method for unique identification of mantle material by its content of primordial helium highly enriched in He³. Similar results have been obtained on the Red Sea brines in which He contents up to 360 times solubility in seawater have been generated by stripping from basalts in the axial trough of the Red Sea.

Drs. Craig, Lupton, and Yu-Chia Chung began a field program in-

vestigating the use of radon and helium as fluid-phase precursors to earthquakes. Hot springs and wells along the major faults in southern California, from San Bernardino to the Mexican border, are being monitored for radon and helium fluctuations that may exhibit precursory behavior. Yoshio Horibe, visiting scientist from the Ocean Research Institute, Tokyo, and Dr. Craig measured the equilibrium deuterium fractionation between CH₄ and H₂ over the temperature range 200-600°C. This exchange reaction can now be used as a "geothermometer" for studying the relationships between these two gases and water in geothermal and volcanic gases, thus supplementing the C¹³ geothermometer for CH₄-CO₂ studies.

Dr. B. L. K. Somayajulu from Ahmedabad, India, and Dr. Craig showed that the Pb²¹⁰-Ra²²⁶ disequilibrium they had previously discovered in deep, ocean water was indeed due to particulate scavenging of lead as they had proposed. Measurements of particulate Pb²¹⁰ activity showed a continuous increase of activity with depth in the South Atlantic, as required by the model. Graduate student Michael D. Applegate obtained similar results from a particulate profile in the North Pacific.

Dr. Chung studied radium variations in the oceans and lakes. Two GEOSECS radium profiles (one in the South Atlantic, the other in the North Pacific) were measured for intercalibration between University of Southern California and Scripps laboratories. The agreement is within the precision of measurements, with no systematic deviation. Also measured were 60 glacier samples collected from the Weddell Sea (surface and bottom-water samples and three shallow profiles). The results indicate fairly uniform distribution in the bottom water. Profiles measured from Lake Tahoe and Lake Tanganyika indicate fairly constant distribution within each lake, but with large differences between lakes. The latter contains ten times more radium than the former. Dr. Chung also participated in a leg of GEOSECS Pacific Expedition in November, 1973. Three papers have been published in the journal *Earth and Planetary Science Letters* during the year.

Dr. Ray F. Weiss, as part of his work in the GEOSECS program, acted as chief scientist aboard R/V *Melville* on GEOSECS Pacific Leg 5, in the central Pacific. Among the major accomplishments of this work was the mapping of the benthic thermocline, or "benthic front"—the surface that marks the boundary between Pacific Deep Water and Antarctic Bottom Water—as the bottom water crosses the equator into the Northern Hemisphere. Whereas the dip of this surface is toward the northeast in the Southern Hemisphere, its dip is toward the northwest in the Northern Hemisphere. This supports the hypothesis that the topography of this discontinuity is controlled geostrophically by the relative northward flow of bottom water. In January, 1974, Dr. Weiss was appointed a member of the GEOSECS Scientific Advisory Council, and he has become a principal organizer and Scripps representative for INDOCHEM, the proposed geochemical study of the Indian Ocean. In addition to his responsibilities for dissolved gas and carbonate chemistry analyses of GEOSECS samples, Dr. Weiss continued earlier studies on the solubilities and physical properties of gases. The solubilities of carbon dioxide and krypton in water and seawater were measured, and the application of these results to natural systems was evaluated by using the thermodynamics of non-ideal gases.

The research work of Dr. Joseph R. Curran continued on the Bay of Bengal, Andaman Sea, and Western Sunda Arc in the northeastern Indian Ocean. Dr. Curran, in collaboration with Dr. Russell W. Raitt, Dr. David G. Moore of the Naval Undersea Center, San Diego, and Dr. John Grow of Woods Hole Oceanographic Institution, completed a successful cruise in the Bay of Bengal and Andaman Sea in October and November, 1973, with collection of underway geophysical data, piston cores, and heat flow. This will complete the planned field studies in the Bay of Bengal and the groundwork for other investigations of the Andaman Sea to be continued during the coming year on Eurydice Expedition. Geophysical confirmation was obtained that the Andaman Sea is presently spreading in a northwest-southeast direction, but the overall tectonic pattern can be seen to be extremely complex. A detailed, relatively high-resolution, seismic survey was made of the offscraping of sediments of the Bengal Fan at the subduction zone west of the Andaman Islands. These studies will be continued on Eurydice Expedition during 1974-75.

Dr. LeRoy M. Dorman recently arrived at Scripps, bringing a Graf-Askaniya sea gravimeter that is on loan from the National Oceanic and Atmospheric Administration (NOAA). The first use was made of the gravimeter aboard the University of Washington's R/V *Thomas G. Thompson* on a seismic refraction survey of the east flank of the East



Extremely fresh pahoehoe (ropy) tholeiitic basalt flows and jointed pillows with glassy crusts are evident in photos taken at a depth of 3,100-3,115 m in central rift of seismically active Central Indian Ridge in western Indian Ocean. Note ripple-marked sediments between outcrops.

Dr. Robert L. Fisher and Judy Clinton

Pacific Rise between the Clipperton and Orozco fracture zones, conducted by Dr. Brian Lewis of the University of Washington.

Shortly afterward, Dr. Dorman led an expedition to the Siqueiros Fracture Zone to study the boundary of different geological ages between sections of the ocean floor. The fact that the fracture zone forms a relatively sharp boundary between relatively uniform sections makes it possible to transform the observed gravity anomaly into the density difference, as a function of depth between the younger and older sections. These density variations with age are important in understanding the energetics of plate motions. Extensive use was made of seismic refraction in studying the area near the fracture zone. Dr. Raitt collaborated with the sonobuoy portion of the program, and heavy use was made of the "pop-up" ocean-bottom seismographs developed by Dr. William A. Prothero.

Dr. Dorman's edge-effect analysis is also applicable to continental margins and is being applied to data from the east coast of Canada by Dr. Charlotte Keen, who was here on sabbatical.

Dr. Albert E. J. Engel and graduate student Allan Divis are studying the interrelations of geologic provinces of the continents. Their work centers on the origin and evolution of the large Proterozoic rock province of Colorado, Arizona, and New Mexico (seemingly formed between 1.7-1.9 aeons ago), adjacent to the very old (>3 aeons) Wyoming province of the continent.

The fundamental problem is that of searching for geological and geochemical evidence that clearly establishes the initial ages and modes of origin of these two adjacent and very contrasting segments of the crust of North America.

Dr. Engel and Dr. Celeste G. Engel are also attempting to characterize the geochemical characteristics and evolution of high temperature and pressure granulites that presumably form important segments of all continental substrate, and to model the nature of any rock magmas that may be generated in these rocks and emplaced in higher levels of the crust.

Dr. Robert L. Fisher, in collaboration with Dr. Celeste Engel, continued the petrographic description and field relation interpretation of igneous rock samples relative to geological-geophysical structural data from more than 4,500,000 km² of the seismically active, variously spreading, ridge system in the western Indian Ocean. In addition to the extremely uniform tholeiitic basalts of shallow occurrence that contribute to magnetic lineation patterns and form seafloor flows and pillows (see illustration), fresh rocks from the cross-fractures being studied by Drs. Fisher and Engel include lherzolite, anorthosite, orthopyroxenites, norite, gabbro, Ti-rich ferrogabbro, granophyric diabase, and late-stage residual dikelets of granitic composition. Large segments, and perhaps all, of the Cenozoic Central Indian Ridge are composed of interspersed, highly differentiated, stratiform bodies of norite, gabbro, and Ti-ferrogabbro. ⁴⁰Ar/³⁹Ar measurements on these plutonic igneous rocks demonstrated an apparent age discrepancy of about one order of magnitude between the intrusive rocks and the overlying basalt. Further evaluation of the ⁴⁰Ar/³⁹Ar method of dating submarine igneous rocks is continuing under Dr. E. C. Alexander of the University of Minnesota.

Long-continuing work with Dr. John G. Sclater, now at the Massachusetts Institute of Technology, was completed with the publication of a definitive paper on the evolution of the east central Indian Ocean and the Ninetyeast Ridge in the *Geological Society of America Bulletin*. Drawing primarily on extensive Scripps data supplemented by Deep Sea Drilling Project (DSDP) results, these authors worked out an evolution for the region from 73°E-102°E, 2°N to 32°S since Cretaceous time as a companion piece to the 1971 publication with Dan McKenzie on the evolution of the Central Indian Ridge. In addition to refining the magnetic chronology west of Ninetyeast Ridge and identifying east-west trending anomalies of Late Cretaceous through middle Eocene age (rather than Jurassic-Cretaceous) east of Ninetyeast Ridge, Drs. Sclater and Fisher delineated several huge, north-south trending fracture zones east of Ninetyeast Ridge, and concluded that the spectacular north-south Ninetyeast Ridge pile did not result from plates passing over a mantle plume or "hot spot" in the plate-tectonics hypothesis sense. They further demonstrate that vast areas east and west of Ninetyeast Ridge spread in concert from at least Anomaly 33b (Late Cretaceous) to Anomaly 12 (Oligocene) time, with a common pole initially near 10°E close to the equator. They conclude peninsular India was joined to Enderby Land in Antarctica during the Early Cretaceous.

Dr. Fisher was co-chief scientist on Leg 24 (Djibouti to Mauritius) of

the Deep Sea Drilling Project in May-June, 1972. Hence, much of the present year was spent preparing manuscripts and assisting DSDP editors in the completion of the Leg 24, *Initial Reports of the Deep Sea Drilling Project*, due for publication in the fall of 1974. Aside from contributing to the individual site reports, Dr. Fisher wrote papers on underway geophysics, and collaborated on igneous rock trace element and on-site survey chapters. Editorial board work continued on the final revisions of the UNESCO-sponsored and internationally prepared *Atlas of Geology and Geophysics of the International Indian Ocean Expedition, 1959-1965*, to be published in Moscow early in 1975. Similarly, work was initiated on preparation of Sheet A'IV, General Bathymetric Chart of the Oceans (GEBCO), fifth Edition, for which Dr. Fisher is coordinator.

The research programs of Dr. Edward D. Goldberg and his associates, Drs. Chin-wu Su, Kathe Bertine, and Ross O. Barnes, and John J. Griffin and Minoru Koide have focused on the transfer processes of natural and pollutant materials from the continents to the oceans, and the chemical reactions involving these materials, especially in surface waters and the interstitial waters of sediments.

Their investigations of the present and past fluxes of plutonium to the ocean system have enhanced man's understanding of natural mobilizations of soil and rock debris. Plutonium and strontium radioisotopes, primarily injected into the environment from the explosion of nuclear devices, have higher fluxes to the oceans than to lands. This is now explained by an atmospheric fallout of both species from the stratosphere to land and sea in equivalent amounts, with some of the species accommodated on materials being transferred to the oceans subsequently.

The primary mode of transport from the continents appears to be through the atmosphere. Studies on coastal and open-ocean sediments, where river-borne entries of these isotopes might have been important, indicated that there is a transoceanic and transcontinental movement of these man-produced radioisotopes. Griffin and Koide participated in this work.

With Dr. Barnes, Dr. Goldberg's studies on the chemical reactions occurring in the waters of sediments under biologically productive waters indicated the production of nitrogen gas, with a subsequent diffusion of this gas from the sediments to the overlying waters. The nitrogen gas was produced from the reduction of nitrate whose origin was both in the overlying waters and in the oxidation of nitrogen-bearing organic matter. The oxidation reactions took place in the strata closest to the seawater, while the reduction of nitrate appears to have occurred at lower levels of the deposit.

With John Griffin, Dr. Goldberg measured the amounts of elemental carbon from plant burning and from fossil fuel combustion in coastal marine sediments off California and Washington. There appears to be little change in fluxes over the past century, thus indicating that management practices in the control of forest and brush fires have had little effect upon these fluxes.

With Dr. Su, Dr. Goldberg has conducted a worldwide survey of halocarbons that are used in the dry-cleaning industry, as aerosol propellants, as solvents, and as degreasers; in airs and in surface seawaters. They are now ubiquitous in such natural domains, and their increased fluxes with time may affect ozone levels in the atmosphere and biological activity in surface seawaters.

The principal research activities of Dr. James W. Hawkins and students working with him have been directed toward understanding the evolution of the oceanic crust, island arcs, and linear volcanic chains in the Samoa-Fiji-Tonga area of the southwest Pacific.

A revised bathymetric chart of the Lau Basin has been finished, as have maps showing sediment thickness and magnetic field intensity. The geochemistry and petrology of seamounts located at the north edge of the Tonga Trench, the Samoan Island chain, and the Louisville Ridge have been studied and used to help interpret crustal evolution and the relationship of these features to the regional tectonic framework.

The Louisville Ridge appears to be a linear volcanic chain, much like the Emperor-Hawaii chain, rather than an extension of the Eltanin Fracture Zone, as suggested by previous studies by other workers. The Samoan chain and adjacent seamounts probably owe their origin to rupture of the Pacific Plate as it is sharply flexed downward into the north end of the Tonga Trench.

Submarine-canyon current-meter records, previously all from the West Coast, now include three canyons along the East Coast of the United States (a NOAA expedition) and north Kauai in the Hawaiian

Islands (a Navy expedition). Here, Dr. Francis P. Shepard found evidence of upcanyon advance of the internal waves that produce the alternating upcanyon and downcanyon flows. He has further confirmation that the alternating flows in deep water have tidal periods. Also, with superposed meters, the times of alternation appear to agree closely at heights above the canyon floors up to at least 30 m. Although the currents in the California canyons have a net downcanyon flow with rare exceptions, the East Coast canyons have net upcanyon flows in about 50 percent of the records. The currents in Hydrographer Canyon, off Georges Bank, have the highest velocities shown on any of Dr. Shepard's records, up to 50 cm/sec, possibly because the tides are very strong on Georges Bank. Records in the outermost limit of valleys off Kauai show very weak currents.

During the past year, results of this work have been published in three scientific journals: *Marine Geology*, *Science*, and *American Association of Petroleum Geologists Bulletin*.

Dr. Jacqueline Mammerickx completed 11 charts on the bathymetry of the South Pacific in collaboration with Stuart M. Smith, Isabel L. Taylor, and Thomas E. Chase. Magnetic data were analyzed concurrently by Drs. Peter Molnar, Tanya M. Atwater, Roger N. Anderson, and Henry W. Menard, and these led to a new assessment of the Cenozoic history of the South Pacific.

Dr. William A. Newman, in collaboration with Dr. H. S. Ladd of the U. S. Geological Survey, Washington, D.C., completed work on Indo-Pacific coral-inhabiting barnacles of Miocene age from deep drillings on Eniwetok and subaerial deposits on Fiji. In light of their earlier work on these organisms from the Caribbean, the results were quite unexpected. In the Caribbean Miocene, all organisms were generalized and were represented by more species than today. One extinct genus, represented by *Eoceratoconcha kugleri*, apparently was in the stem-line of the group. In contrast, the fossils from Eniwetok and Fiji represent advanced extant genera previously believed not to have evolved until the Plio-Pleistocene. Thus, while the coral barnacles in the Caribbean began to decline shortly after they appeared, those of the Indo-Pacific underwent an explosive evolution during the same period and have maintained a high diversity ever since.

Other work by Dr. Newman in the Indo-Pacific included completion of a study on *Darwin Guyot, the Pacific's Oldest Atoll*, in collaboration with Drs. Ladd and N. F. Sohl. The report was presented at the Second International Symposium on Coral Reefs held in Australia and will appear in the *Proceedings*. Numerous central Pacific Cretaceous guyots may have had an atoll-like form, but Darwin Guyot is the only one known. It has been possible to identify the organisms in good part responsible for it, because unlike most guyots, Darwin is too small to have accumulated a significant cap of pelagic sediments, so that "reef-rim and lagoonal regions" were accessible to rock dredging.

William R. Riedel and Annika Sanfilippo continued and expanded their investigations of the biostratigraphy, evolution, and taxonomy of Cenozoic radiolarians from the Caribbean; of late Neogene sequences in the tropical Pacific and central Indian Ocean; and of Cretaceous radiolarians predominantly from the northwestern Pacific, but also from the Caribbean, northwestern Atlantic, and Indian Ocean. These studies were based on samples obtained by the Deep Sea Drilling Project, supplemented by samples from land-based localities in Europe, the Caribbean, Australia, Indonesia, and California.

The examination of Cretaceous radiolarians resulted in a coarse, widely applicable, radiolarian zonation that divides the Cretaceous into seven parts. This attempt at a Cretaceous radiolarian zonation rests on much less secure foundations than does the zonation of the Cenozoic. The fundamental reason for this is the lack of well-preserved assemblages, particularly in long sequences. Thus, it is not yet possible to determine phyletic relationships, a fact that would greatly aid the stratigraphy. Other factors are the uncertainty of some age assignments based on calcareous microfossils, and the scant understanding of the geographic locations of parts of the sea floor through the Cretaceous, with the resulting difficulty in determining which differences between assemblages may be caused by biogeography, rather than age.

Riedel and co-workers have expanded and intensified efforts to use microscopic fish skeletal debris (ichthyoliths) as a reliable tool to date otherwise unfossiliferous sediments, particularly pelagic red clays. A pragmatic, non-Linnean procedure for describing these microfossils has been developed and used to determine 120 different forms in 195 samples, dated on the basis of other microfossils. Of these 120 forms recorded, about 60 offer some immediate promise of stratigraphic ap-

plicability in having coherent and limited time-ranges. Some of the sediments from Legs 26, 30, and 32 of the Deep Sea Drilling Project, lacking other microfossils, were approximately dated on the basis of their contained fish skeletal debris.

Cretaceous samples from localities in Europe have been investigated, and additional samples have been collected for further study. In addition to continuing their stratigraphic work, they also pursued inter-related lines of investigation concerning factors limiting preservation and reworking of ichthyoliths.

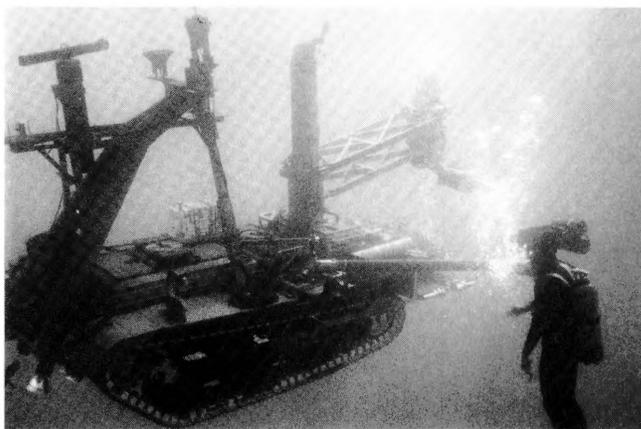
The curatorial staff maintains extensive marine geological collections of sediment cores and dredged rocks and their general description, and makes information and samples available to investigators and agencies interested in the sea floor. The core-describing activity has resulted in approximately 193 core descriptions being produced and published as part of the Scripps reference series, published in the journal literature. The major rock collections that were at Camp Elliott have been described, cataloged, and moved to storage in Seaweed Canyon.

GEOSECS

GEOSECS is an acronym for Geochemical Ocean Sections Study, a multiinstitutional program supported by the International Decade of Ocean Exploration of the National Science Foundation. Two GEOSECS groups are in residence at Scripps: the GEOSECS Operations Group, directed by Arnold E. Bainbridge and located in Sorrento Valley, and Dr. Harmon Craig's laboratory group on the campus. Dr. Craig is a member of the GEOSECS Executive Committee, which directs the program. Joseph L. Reid and Dr. Ray F. Weiss of Scripps are members of the program's Scientific Advisory Council.

During 1973-1974, the GEOSECS Pacific Expeditions were carried out aboard R/V *Melville*. The expedition program consisted of ten legs that provided an east-west section from San Diego to Tokyo, a north-south section from the Bering Sea to the Antarctic Rise, roughly along 180° longitude, and a second north-south section in the eastern Pacific, roughly along 125°W. The complete Pacific track and the stations occupied are shown in an accompanying illustration. Dr. Craig was expedition coordinator for GEOSECS Pacific, and served as chief scientist on Legs 1 and 8; and Dr. Weiss was chief scientist on Leg 5. Bainbridge and Dr. Yu-Chia Chung served as scientists on Legs 1 and 4, respectively. Other Scripps staff members who served as scientists in the Pacific include Arnold W. Mantyla: Legs 4, 5, 8, and 10; Robert T. Williams: Legs 6 and 9; Manuel Fiadeiro, a graduate student: Legs 5 and 6; and Dr. William C. Patzert: Leg 9.

Fred S. Dixon was a scientist on Legs 1, 7, and 8. On Leg 1 he was



George Wilson assists in descent of Scripps's RUM to the ocean floor, laden with a variety of sampling devices. Hardware included cameras, box corers, traps, and water bottles used in the Quagmire Expedition for intensive sampling of marine fauna at a 1,200-m depth in the soft mud of the San Diego Trough, located about 15 miles off San Diego. RUM is controlled from the ocean surface by a console unit housed aboard Scripps's ORB. The pincer on RUM's manipulator arm is hidden by diver's bubbles.

Charles Alexander

principally concerned with shakedown problems; on Leg 7 he conducted an extensive heat-flow survey along the Antarctic Rise. On Leg 8 Dr. Craig and Dixon carried out a bathymetric survey of the 8,000-square-km area between the Valerie Guyot chain and the south end of the Louisville Ridge at 32°S, together with dredging by Dixon. Five crossings of this area showed that it consisted entirely of smooth abyssal plain at 2,600 fathoms, rather than a chain of seamounts as had been suggested.

A primary aim of the Pacific program was the study of the "benthic front," the deep-density discontinuity and stability maximum that separates the Antarctic Bottom Water from the overlying Pacific Deep Water in the South Pacific. This front is responsible for the "induced extrema" that characterize salinity, oxygen, and geochemical profiles in this part of the ocean. The benthic front was mapped in detail in the Samoan Basin and in the Southern Basin between the Tonga-Kermadec Trench and the Circumpolar water. Drs. Craig and Chung and Fia-deiro had predicted (1972) that the dip of the front would reverse in crossing the equator to the North Pacific, and this was verified by Dr. Weiss in a survey on Leg 5. The major result of this work is that bottom-water flow in the South and North Pacific can be traced in detail by simply mapping the benthic front discontinuity. Equally important is the fact that the characteristics of T, S, and geochemical profiles can now be understood in detail, and effects of "induced extrema" can be distinguished from effects of *in-situ* production and consumption.

At the operations group headquarters, the main effort is directed toward preparing the data collected on all GEOSECS expeditions and the publication of results of samples returned from the ship. A 12-volume set of atlases is proposed that will contain colored sections, property-property plots, data tabulations, and analytical and data techniques. The first volumes are scheduled to be in the hands of the printers by January, 1975.

Other activities include the rework of mechanical and electronic shipboard equipment in preparation for the next major ocean expedition, expansion of the computer data bank and interactive terminal system, and expansion of the terminal system to principal investigators across the country via the ARPANET (Advanced Research Projects Agency Network). The STD-0₂ probe system and other equipment and personnel have been requested by oceanographers at Scripps and other institutions for use in projects ranging from major expeditions in the North Atlantic to ice-island surveys in the Arctic.

A complete set of the GEOSECS Pacific leg reports, including all shipboard measurements (T, S, O₂, nutrients, total CO₂, alkalinity, gas chromatography, and radon) and detailed STD and discrete profiles, is on file in the Scripps Library. The third set of GEOSECS collected papers, including C¹⁴ and tritium data for the North Atlantic, appeared in *Earth and Planetary Science Letters*.

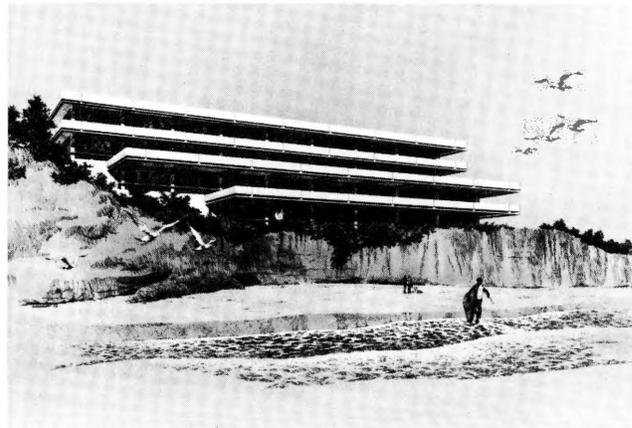
Planning is in process for the GEOSECS Indian Ocean Program (INDOCHEM) on which it is proposed to begin expedition work early in 1977. Dr. Weiss is the Scripps representative on the INDOCHEM planning committee; inquiries concerning possibilities for shipboard and laboratory participation in the program are invited and should be addressed to him. A strong emphasis on suspended particulate matter studies is planned for the Indian Ocean.

Marine Biology Research Division

Investigations in the Marine Biology Research Division embrace experimental and descriptive biological disciplines, including physiology, biochemistry, microbiology, developmental and systematic biology, and ecology of the sea. Many of the studies are comparative in nature, and structures, events, or processes are examined in a wide range of organisms, both marine and terrestrial. 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.

The work of Dr. William A. Newman and associates touched upon a variety of problems concerning barnacles and coral reefs. Further investigations utilizing insect juvenile hormone mimics (JHM) by Edgardo Gomez resolved the perplexing problem of sex determination in *Balanus galeatus*, a remarkable barnacle commensal on certain gorgonians in which cross-fertilizing hermaphrodites are accompanied by complementary males. *In vitro*, larvae will undergo metamorphosis only when appropriate substrates are provided, and the sexes appear in a ra-

tio of approximately 1:3. The same ratio can be achieved when metamorphosis is induced by JHM, in the absence of an appropriate substrate. This conclusively demonstrates that sex in this organism is genetically rather than environmentally determined. This fact materially assisted in understanding the population dynamics of the barnacle, the subject of Dr. Gomez's doctoral thesis in which mature males consistently outnumber hermaphrodites in the field.



Construction on first major building erected on campus since completion of Physiological Research Laboratory in 1965 began with groundbreaking March 20, 1974, for the \$3.7-million Marine Biology Research and Instruction Building, just north of Scripps Pier. Participating in ceremonies were, from left, UCSD Chancellor William D. McElroy; Eugene Weston, of the architectural firm of Weston, Liebhardt, and Forester, AIA; Director Nierenberg; and K. G. Siegmund, of William Simpson Construction Co. Architects' rendering shows how structure will set back from Pacific into bluffs overlooking ocean, more clearly defined in photograph showing early construction phase. New building will permit better coordination and interaction between scientists and students and more efficient use of classrooms and laboratory facilities, currently scattered throughout the Institution. Completion date is set for 1976.



Dr. Carl Hubbs compares his black barracudina—a relative of the barracuda—with one (and the only other specimen on record) described in reference book. Seven-year-old Richard Baker, Santee, California, caught this denizen of the deep by hand in very shallow coastal waters off San Diego. Richard's "catch" was more than a foot long and almost four inches longer than the first fish, which was caught in 1960 off San Clemente Island. Richard's reward was a book on fish that had been edited by Dr. Hubbs, who has studied fish for more than 50 years. The black barracudina, now preserved in isopropyl alcohol, has joined the more than 1,000,000 specimens in Scripps's marine vertebrate collection.

Jackie Janke

Concerning coral reefs, Thomas Dana enlarged upon the hypothesis—at a symposium on the biology of *Acanthaster planci* held in Guam by the Pacific Science Association—that sudden reductions in food availability contribute to massive aggregations of this starfish. Biologists have been reluctant to accept the fact that typhoons damage reefs; other investigators have reported, however, that heavy rainfall, as well as physical damage associated with tropical storms, has apparently been responsible for initiating aggregations.

Dr. Newman joined forces with Peter Jumars and Arnold Ross and reported on their analysis of diversity trends in coral-inhabiting barnacles of the world at the Second International Symposium on Coral Reefs. Generalized members of these obligate commensals proved to hold significant correlations with distributional and host exploitation indices. This indicates that as larvae they are vagile, eurytopic forms, and as such tend to exploit corals of geologically greater generic age than specialized forms. Similar patterns are likely to be found in other reef organisms.

During sabbatical leave, Dr. Newman spent six months at the Plymouth Laboratory, England, where he completed an article on Cirripedia for the *Encyclopaedia Britannica* and a chapter on California cirripeds for the forthcoming revision of *Light's Manual* (U.C. Press). He also had the opportunity to study two remarkable, deep-sea members of the cirriped orders, Ascothoracica and Acrothoracica. The former, collected at more than 5,000 m in the South Atlantic by Woods Hole Oceanographic Institution, proved to be a free-living, semiparasitic member of the predominantly parasitic order. The study shed light on the long perplexing problem of how certain solitary endoparasitic

forms become fertilized. The Atlantic species turned out to be protandric, the protanders apparently being capable of reciprocal copulation while in the plankton before infecting a host and becoming female. If the same system is operative in the solitary endoparasites, and there is every indication that it is, then the riddle is solved.

Deep-sea benthic community studies were the major effort in Dr. Robert R. Hessler's laboratory. These concentrated on two basic environments: the eutrophic bathyal, as typified by the San Diego Trough, and the oligotrophic abyss, as seen in the central North Pacific gyre.

During November, 1973, this laboratory supervised Quagmire Expedition, a cooperative venture of investigators from several institutions. With the support of the Marine Physical Laboratory, R/P ORB (Ocean Research Buoy) was taken to a soft mud locality at 1,200-m depth in the San Diego Trough. MPL's RUM (Remote Underwater Manipulator) was operated there for a month of intensive sampling. In order to obtain a perspective on the community and its environment, a variety of sampling devices, including cameras, box corers, traps, and water bottles was used. The resulting samples will yield information on the entire fauna, from fish to bacteria, and in such a way that considerable inter-correlation is possible.

Use of RUM has allowed a high level of sophistication and accuracy never before achieved in deep-sea biology. Through deployment of transponders, it was possible to determine the position of every sample, thus permitting careful spatial distribution studies. The mechanical arm, in combination with a video monitoring system, permitted each sample to be taken in a deliberate and careful way, so that the usual sampling biases could be avoided or at least assessed. The general flexibility and long-duration working capability of the system gave the opportunity to perform tasks heretofore exceedingly difficult or impossible. Among these were *in situ* measurement of fish respiration, multireplicated community respiration, microbial nutrient uptake analysis, macrofaunal trapping, and sediment disturbance studies. In total, while not perfect, Quagmire Expedition was the most complete and detailed analysis of a deep benthic community ever made.

While the Quagmire project consumed most of Dr. Hessler's laboratory time last year, the scientists were able to continue their efforts in two other areas: community analysis of the abyssal oligotrophic benthos in the central North Pacific, and studies of the systematics, biogeography, and evolution of deep-sea isopod crustaceans.

Marine food chains involve transfer of energy from one organism to another by grazing of phytoplankton and predation of increasingly larger animal species. The links in this chain are the nutritionally rich compounds stored by each animal as its energy reserves. The study of nutrition in zooplankton and fishes has attracted the interests of Dr. Andrew A. Benson and his group. They had earlier discovered that wax, not ordinary fat, is the major medium for metabolic exchange in the sea. Long known, but hardly understood, wax has appeared as a primary source of energy for most of the small fishes and many of the larger ones in the ocean. All animals below 1,000 m seem to be producers or consumers of wax, a compound like fat but much simpler in molecular construction. The efficiency of wax digestion and metabolism was first studied in small salmon and anchovies, since their diet of copepods can be as high as 70 percent liquid wax. The digestion of wax appears to involve enzymes not previously recognized in human metabolism. Its study has revealed the importance of dietary adaptations and requirements throughout the food chain.

An example of wax digestive proficiency was discovered by Dr. Benson in the Crown-of-Thorns starfish, *Acanthaster*. Its diet of coral is exceptionally rich in a wax, cetyl palmitate, which the coral system accumulates. The wax-digesting lipase of *Acanthaster* was found far more effective than that of other marine animals. Other starfish were unable to digest wax. *Acanthaster's* success in destroying many tropical coral reef areas is understandable and some possibilities for control of this marauder can now be considered.

Dr. Denis L. Fox completed, and submitted for publication, through prior agreement with the University of California Press, the revision and considerable supplementation of his book *Animal Biochromes*, first published in 1953 by the Cambridge University Press.

In consequence of his participation at the International Symposium on Flamingos, held in July, 1973, at the Wildfowl Trust in Slimbridge, Gloucester, England, Dr. Fox, in collaboration with K. C. Lint, curator of birds at the San Diego Zoo, conducted an extended study of a blood plasma-carotenoid loss by flamingos when segregated and fed a basic

diet lacking β -carotene, canthaxanthin, or any carotenoid known to be assimilated by the birds and utilized in their maintenance of pink-to-red pigmentation of their feathers and tarsal skin. A significant observation was the gradual restoration of the red pigment, canthaxanthin, into the plasma, when the birds' diet was supplemented with finely shredded, fresh, barley-greens as a source of β -carotene. The report is in press for the 1975 issue of the *International Year Book*.

Research in Dr. David Epel's laboratory has centered on the changes that occur in the egg when embryonic development is initiated at fertilization. A major breakthrough this past year concerned the primary events leading to metabolic activation. The unfertilized egg can be considered a metabolically repressed cell. Contact with the sperm depresses the egg metabolism and activates new metabolism leading to the formation of a new individual. In collaboration with Dr. Richard Steinhardt from UC-Berkeley, Dr. Epel found that the primary event is most likely the release of intracellular calcium. Specifically, they have found that they can parthenogenetically activate sea-urchin eggs with the ionophore drug, A23178. This compound binds to the plasma membrane and specifically abolishes the selective permeability of the membrane for divalent cations. When applied to eggs, they are artificially activated to undergo embryonic development. It appears that this compound is a general agent. Besides echinoderms, it activates eggs from such diverse organisms as molluscs, tunicates, amphibians, and even mammals.

Other important findings concerned the mechanisms of the block to polyspermy. In order to preserve the genetic continuity of an organism, it is mandatory that only one sperm enter the egg. This is a formidable problem, since, at fertilization, the egg can be "attacked" by numerous sperm. There exist powerful mechanisms to exclude these supernumerary sperm, and significant progress has recently been made in understanding the mechanisms of this exclusion. Dr. Edward Carroll, Jr., a fellow of the Population Council, and Mia Tegner, a graduate student, have provided important new information. Previous work from the laboratory had shown that an enzyme released by the eggs at fertilization destroyed sperm receptors on the outer egg surface as part of the block to polyspermy. Tegner has carried out important studies on the biology of the block, and Dr. Carroll has characterized the nature of the enzymes involved in the block. He has found that there are two separate proteases released by the eggs with distinctly different biological properties. One of these is involved in elevating the membrane of the eggs at fertilization; the other is involved in destroying the sperm receptors.

The memoir on the "Hydrographic History and Relict Fishes of the North-Central Great Basin" appeared in print during the year in the *California Academy of Science, Memoirs*, Vol. VII (on the 40th anniversary of Dr. Carl L. Hubbs's initial researches in that area). Another project of about equally long status; namely, an analysis of the systematics and distribution of the freshwater fish fauna of eastern Mexico, was brought toward fruition during Dr. Hubbs's research visits at the University of Michigan. Substantial progress was made toward early joint publications on the "Documented List of the Fishes of California, with an Analysis of the Fauna"; on the systematic and oceanographic revision of the scomberesocid fishes (sauries) of the world; on the first several of a major series of systematic and distributional studies of the Myxinidae (hagfishes) of the world (in collaboration with Charmion B. McMillan); and on the Pacific species of the fish genus *Eucinostomus* (mojarra). Studies were also continued on the achirid soles and various other marine fishes, and on marine mammals.

Robert L. Wisner, continuing on a volunteer basis with Dr. Hubbs, brought to near completion his systematic and distributional analysis, for the Naval Oceanographic Office, of a major group of pelagic fishes (the Myctophidae, or lanternfishes) of the eastern Pacific. He is also the collaborator on the monograph of the sauries.

Studies of enzymic mechanisms of environmental adaptation were continued in the laboratory of Dr. George N. Somero. Work focused on several of the manners in which variations in enzyme properties adapt organisms for different thermal regimes. A comparison of enzyme polymorphism (genetic variability) in 13 species of marine fishes was conducted jointly with Dr. Michael Soule of the UCSD Department of Biology. No differences in levels of allelic or isozymic polymorphism were found that could be correlated with the degree of thermal variation in the fishes' habitats. This discovery is not consistent with the hypothesis that adaptation to variable habitats favors increased genetic polymorphism.

In investigations of the thermodynamic functions of catalytic activa-

tion, it was found that a general correlation exists between the ability of an enzyme to reduce the free energy of activation of its reaction and the degree to which the organism is adapted to metabolize at low temperatures. The structural bases of this enhanced catalytic ability by enzymes of cold-adapted organisms is under continued study. Data suggest that the abilities of enzymes of cold-adapted species to reversibly form and break so-called "weak bonds," such as hydrogen bonds within the protein, can account for the observed thermodynamic differences. These structural thermodynamic studies are being conducted jointly with Philip S. Low, a Scripps graduate student.

Studies of enzymic adaptation to hydrostatic pressure have shown that enzyme-ligand interactions are a primary locus of perturbation by extremes of pressure.

In the laboratory of Dr. Theodore Enns, the mechanisms of carbon dioxide transport in animals and plants are being analyzed. In collaboration with Dr. Esther Hill of the UCSD School of Medicine, carbon dioxide diffusing capacities of mammalian lungs have been measured. The role of the enzyme, carbonic anhydrase, in carbon dioxide excretion has been demonstrated.

The action of carbonic anhydrase in photosynthetic production of marine plants, the first step in support of all ocean life, is under investigation. Reduction of growth resulting from its inhibition has been demonstrated in some salt-water plants.

Dr. Elizabeth Kampa Boden is continuing investigations of photoenvironment and the behavior of photoregulated, mesopelagic animals. Addition of neutral density filters to the bathythermo-irradiance meter has allowed extension of midday determinations of the spectral characteristics of transmitted daylight into the surface layers, and has revealed the presence of a marked photocline in the water column at 25 stations in the Atlantic and the Pacific—the most recent three in the North and South Equatorial currents and the Equatorial Counter-current during Krill Expedition in 1974.

The photocline had not been evident previously, because the irradiance meter was too sensitive for near-surface work at midday. Other workers have been concerned only with light in the surface waters, or, if their observations extended into mid-waters, they disregarded the color of light measured.

At a typical oceanic station, near-surface waters are relatively clear. At some depth (50–125 m), attenuation of wavelengths shorter than 460 nm and longer than 490 nm increases abruptly, and spectral distribution curves become appreciably narrower. Photocline depth coincides with that of the thermocline. The sharper the thermocline, the more pronounced the photocline. Below the photocline, the waters are again more transparent to the longer and shorter wavelengths, and the family of attenuation curves becomes more nearly uniform in slope.

Although seawater itself acts as a monochromator, it is in the photocline that the greatest modification of the color of light occurs. The depth correspondence between photocline and thermocline indicates that the phenomenon is occasioned by absorption and scattering of light by particles—living and detrital trapped in a density barrier.

Research in the laboratory of Dr. Francis T. Haxo continued to focus on dinoflagellates, important primary producers in the marine realm. In continuing collaborative studies with Dr. H. Rapoport, UC-Berkeley, of toxic dinoflagellates, *Gonyaulax polyedra*, the common bloom dinoflagellate of southern California coastal waters, failed to show any significant toxicity in bioassay tests and by specific chemical assay for saxitoxin. Small numbers of a chain-forming *Gonyaulax*, presumably *G. catenella*, were observed in the local plankton during the spring; laboratory isolates proved to be toxic. Should this organism indeed be the saxitoxin-producing *G. catenella*, it will be important to evaluate the environmental circumstances and physiological tolerances which led to the occurrence of this cold-water dinoflagellate (even in very modest abundance) in the warmer waters of southern California.

Chloroplast pigment composition within different algal groups has long been useful in reinforcing postulated taxonomic affinities. Two recently completed studies by Dr. Haxo on a wide variety of dinoflagellates (in collaboration, respectively, with Dr. Shirley W. Jeffrey, of the Commonwealth Scientific Industrial Research Organization, Australia, and Dr. Synnøve Liaaen-Jensen, University of Trondheim, Norway) have helped to define the range of pigment composition in the group, and to place minor constituents on a more firm chemical basis. A surprising exception to the usual pattern has now been found in the Florida red-tide dinoflagellate, *Gymnodinium breve*, in that neither peridinin (nor fucoxanthin), the characteristic dinoflagellate carote-

noid, could be detected. The phyletic and physiological implications of this finding are subjects of future study.

In other studies, Nancy Withers, a graduate student, has obtained definitive evidence for the presence of the rare γ -carotene, as well as carotenogenic precursors, in extraplastidic granules of *Peridinium foliaceum*.

Peridinin, as well as the extractable peridinin-chlorophyll *a* protein complex of dinoflagellates, has been found by Barbara Prezelin, a graduate student, to vary under different conditions of laboratory culture; this provides an opportunity to evaluate the function of carotenoid-chlorophyll complexes in dinoflagellate photosynthesis.

During the past year a variety of projects was under investigation in the laboratory of Dr. Ralph A. Lewin. Dr. Colin Franker, on sabbatical leave from UCLA, studied mutagenesis in the apochlorotic marine dinoflagellate *Cryptothecodinium cohnii*, specifically selecting for temperature-sensitive and other mutants impaired in their ability to swim, to undergo normal cell division, or to synthesize the normal carotenoid pigments, intracellular polysaccharides, or essential metabolites, such as amino acids and nucleotides. Such mutants are being used to initiate research on the genetic biology of this organism.

In collaboration with Dr. Lewin, Dr. Meinhard Schultz-Baldes (Institut für Meeresforschung, Bremerhaven), sponsored by a research grant from the Deutsche Forschungsgemeinschaft, is now studying lead accumulation in marine planktonic algae, using atomic absorption methods to analyze both media and cells. He has found that the diatom *Phaeodactylum tricornutum* absorbs Pb in two phases, one rapid, one slower, the latter phase being associated with an irreversible absorption of this ion inside the cells.

Dr. Joan G. Stewart studied the effects of the addition of Pb to the medium on growth and pigmentation of four species of red algae in culture. The Pb ion evidently inhibits the rate of cell division, while leaving cell pigmentation, morphogenesis, and reproductive processes relatively unaffected. She has also continued her observations on the development of subtidal red algae under various controlled environmental conditions.

Harry Ridgway, a graduate student, is studying the mechanism of gliding movement in an obligately marine flexibacterium, *Flexibacter polymorphus* Lewin. Both K and Ca ions are required for movement. Studies using various metabolic inhibitors have indicated that the energy for gliding may be provided by ATP or by some intermediate in oxidative phosphorylation.

Dr. Lewin has been looking into two phenomena: (1) the accumulation of manganese dioxide around the zygospore walls of a new species of *Chlamydomonas*, recently isolated in the vicinity of Scripps Institution; and (2) a facultative symbiotic association between didemnids (calcified colonial ascidians) and a unicellular alga of questionable affinities. (It seems to combine a prokaryotic organization, like that of a blue-green alga, with pigmentation closer to that of a green alga.)

Early studies in Dr. Benjamin Volcani's laboratory on the role of silicon in diatoms showed that this element is not biologically inert, as was generally thought, but actively participates in a range of fundamental metabolic processes. In the past few years other researchers have demonstrated that silicon is essential for the formation of bone, connective tissue, and cartilage in mammals; through its complex relations with hormones, cholesterol and other lipids, it may be a factor in atherosclerosis, and may inhibit as well as promote calcification. Moreover, as a "universal pollutant" in the form of talc and asbestos, silicon is now known to be both fibrogenic and carcinogenic.

Dr. Volcani and his associates have therefore widened their focus, and are using the diatom as a model experimental and "reconnaissance" system for exploring the biochemical role of silicon in the cell and then testing their findings in rat tissues and mammalian cells.

Dr. Cornelius W. Sullivan, carrying out a detailed study on cytoplasmic diatom membranes, has further characterized the ion-dependent ATP-hydrolyzing activities in *Nitzschia alba* membranes and mitochondria on the basis of substrate specificity, divalent cation requirements, ion activation, kinetic constants, and sensitivity to inhibitors. Ten different activities were thus distinguished, but polyacrylamide gel electrophoresis indicates that the activities probably represent four basic enzymes with varying catalytic capabilities: (Mg^{2+})-dependent nucleotidase, (Mg^{2+})-dependent monovalent cation-stimulated ATPases, (Mg^{2+})-dependent anion-stimulated activities, and (Ca^{2+})-dependent activities.

Dr. Charles W. Mehard is continuing his studies of Si-transport in

diatom and rat liver mitochondria to determine the "Si-pump"; in addition, using electron-probe X-ray microanalysis, he has found electron-dense silicon granules in freeze-substituted sections of rat and diatom mitochondria. Isolated granules from liver, spleen, and kidney mitochondria, separated into two fractions, gave (1) a strong Si-, low P-, and trace Ca-signal in the heavy (10,000 x gravity) fraction, and strong P-, low Ca-, and low Si-signal in the light (30,000 x gravity) fraction. The presence of silicon in mitochondrial granules suggests that the mitochondria may participate in mineralization; *i.e.*, silica wall formation in diatoms and bone formation in animals.

John Paul, a graduate student who is working on photorespiration in diatoms, has demonstrated for the first time that in *Cylindrotheca fusiformis* and the apochlorotic *N. alba*, the enzyme system that oxidized glycolic acid (glycolate dehydrogenase) is located in the mitochondria.

Since previous studies in this laboratory have shown that silicic acid is involved in the synthesis of DNA and thymidylate kinase, Thomas Okita, also a graduate student, is carrying out a detailed investigation of the role of silicon in the formation of thymidylate kinase in synchronous cultures of *C. fusiformis*.

Dr. Claude E. ZoBell has continued to investigate the microbial oxidation of oil at low temperatures such as occur in the deep sea and at high latitudes. Samples being studied have been obtained from the deep sea and the North Alaska Slope. In collaboration with Dr. J. Kim of Long Beach State University, he published an account of the occurrence and activities of cell-free enzymes in oceanic environments. This appeared in the Proceedings of the US-Japan Conference in Marine Microbiology as a book entitled, *Effect of Ocean Environment on Microbial Activities*, which was dedicated to Professor ZoBell for his pioneer work in this field.

Under the co-chairmanship of Dr. ZoBell and Dr. Angelo F. Carlucci, Erik Hartwig completed his doctoral dissertation entitled, "Physical, Chemical and Biological Aspects of Nutrient Exchange Between the Marine Benthos and the Overlying Water."

During the past year, Dr. Nicholas D. Holland was on sabbatical leave in Plymouth, England, where he did extensive work on the light- and electron-microscopic description of gametogenesis, fertilization, and the cortical reaction in the Japanese feather star, *Comanthus japonica*.

Marine Life Research Group

The Marine Life Research Group (MLRG) under the direction of John D. Isaacs has conducted research in a variety of areas the past few years. Studies have been carried out in many parts of the world ocean. Although the principal focus has been on the California Current System and the North Pacific Central Gyre, work also has involved the coasts of Latin America, the Indian Ocean, the Peru-Chile Trench, and Antarctica, and it has included research in pelagic communities, varved sediments, deep-sea photography, currents, deep circulation, deep scattering layers, food webs, and the development of new sampling systems.

CalCOFI Atlases

MLRG participated in the California Cooperative Oceanic Fisheries Investigations (CalCOFI), a multiagency study of the California Current System that involves studies by the California Academy of Sciences, the National Marine Fisheries Service, the California Department of Fish and Game, and, earlier, the Hopkins Marine Station of Stanford University. Its continuing contribution is the conduct and analysis of periodic oceanographic and marine biological surveys of the California Current System that are conducted every three years. Data and results of the analyses are contained in the CalCOFI Atlas series that now encompasses 19 volumes.

Four atlases were published during the past two years, three of them concerning the distribution of organisms of the California Current: one about mesopelagic fish larvae, one on euphausiids, and one about calanoid copepods. The fourth atlas, *Release and Recovery Records of Drift Bottles in the California Current Region 1955 through 1971*, was compiled by Fred J. Crowe and Richard A. Schwartzlose and based on 17 years of data. In late 1954, MLRG began using drift bottles to study seasonal variation in the inshore portion of the California Current. During

the intervening years, 148,384 drift bottles were released and 4,994 were recovered. The percentage of recovered drift bottles varied from zero for some months to as high as 23 percent. The northernmost return was from Montague Island, Alaska, the southernmost from an area just north of Acapulco, Mexico, and the westernmost from the island of Hawaii. One uncontrollable factor influencing the frequency of the drift bottle recoveries and interpretation of the results is the intensity of human traffic along the coastline. The results from drift bottle studies of inshore currents on the Pacific coast of British Columbia, Oregon, California and Baja California, however, demonstrate their usefulness as indicators of the direction of surface flow. For example, few other data show as clearly the presence of the Davidson Countercurrent during the late fall and winter months.

Deep Circulation

Joseph L. Reid studied the circulation of the Pacific Ocean and the south Atlantic Ocean. Published results of the Boreas Expedition, carried out in January-April, 1966, in the northwest Pacific, the Bering Sea, and the Okhotsk Sea, have shown that convective overturn extends to no more than 150 m in depth even in midwinter, and in much of the area to less than 100 m. The characteristic low temperature and salinity at the surface are transmitted to greater depths (and then laterally throughout the North Pacific as Intermediate Water) by mixing through the pycnocline rather than by convective overturn.

At somewhat lower latitudes, a shallower salinity minimum is found in both the North and South Pacific above the Intermediate Water salinity minimum. These shallower salinity minima originate in the equatorward eastern boundary currents along both North and South America. They extend westward with the extension of these currents north and south of the equator, and can be detected as far as the Philippine Islands north of the equator.

Measurements of flow and water characteristic in the abyssal Pacific, made near Samoa, have shown not only an abyssal northward flow of water near 5,000 m in the deep and narrow Samoan Passage, but a southward return flow of water near 3,000 m. This suggests that some of the deeper waters of the North Pacific may leave the Pacific by passing southward along the Tonga-Kermadec Ridge into the Antarctic Circumpolar Current.

Dr. William C. Patzert is working with Reid to describe the circulation of the various water masses found in the southwestern Atlantic Ocean. Among the new findings as a result of the Cato Expedition of 1972 are relationships between the deep high-stability layers found in the water column and large-scale circulation.

The results of Dr. Patzert's earlier studies on the seasonal variability in the circulation of the Red Sea and its relation to the monsoon oscillations over the Indian Ocean have been reported, and two studies of the flow around mid-ocean islands have been published.

During April-May, 1974, Dr. Patzert was associate chief scientist aboard R/V *Melville* for GEOSECS Pacific Expeditions Leg J, and is currently analyzing two long sections of closely spaced XBTs from the expedition for evidence of baroclinic instability as a mechanism for mesoscale eddy formation.

A preliminary study of sea-surface temperatures from coastal and island stations has been initiated. In the beginning, the amplitudes and phases of anomalies will be viewed to understand the coherence along the eastern oceanic boundary and out to the island stations. The results from these continuous records should indicate a plan to analyze the offshore data from the CalCOFI cruises. The ultimate objective of this work will be to describe and understand the longer-term fluctuations at the eastern boundaries, in general, and along the California coast, in particular.

Deep Scattering Layers

Some deep organisms scatter sound and are recorded on echo sounders as a continuous layer. These layers, which have important scientific, fishery, and military applications, have often been mistaken for bottom echos—the "phantom bottom" in popular literature. One characteristic activity of the deep scattering layers (DSL) is the vertical migration of many of its components. They sink near sunrise and rise near sunset, and thus suggest daily, light-instigated movement of some of the organisms, ranging as much as 700 m, although coexisting static layers are

commonly observed in the world ocean. Other quantities such as temperature, dissolved oxygen, and chlorophyll concentration have also been associated with the behavior of the layers.

For two years, Sargun A. Tont has been studying the wealth of acoustic records that have been accumulating at Scripps. Accompanying oceanographic information has been periodically reported in Scripps data reports by various investigators, but up to now no complete survey has been made from all the records.

Tont has classified the layers with respect to their migratory behavior and the biotic regions that they occupy. The results have been plotted on a series of 27 maps, and a statistical analysis of the data is nearing completion. It is hoped that this study will give important clues to the behavior of the layers and also predict the distribution of the layers in regions in which no acoustical data are yet available.

Additional research is being done on the idea proposed by Isaacs earlier, and verified successfully in the California Current region by Isaacs, Tont, and Dr. Gerald L. Wick; namely, that as a result of vertical migration, the organisms that constitute the DSLs are preferentially transported into the areas of high productivity.

Biological Studies

Dr. Edward Brinton, in collaboration with Margaret D. Knight and Tarsicio Antezana, studied euphausiid crustaceans and have extended their research to include life histories and details of larval development of important species occupying the region of the California Current and the corresponding coastal waters off western South America. The nearshore part of the California Current system appears to sustain a more homogeneous and self-sufficient biota than had been generally supposed, as evidenced by geographical continuity in populations of the temperate species *Euphausia pacifica* and *Nematoscelis difficilis*.

Rates of recruitment, growth, and production of euphausiids are associated with 6–12-month life cycles that, even to the south of Point Conception, remain strongly geared to the seasonality of environmental processes. There is increasing evidence connecting the degree of success of a cohort to the timing of its initiation in relation to timing of habitat events; e. g., perturbations in temperature, speed, and direction of transport. Further, it has appeared possible to learn something about the extent and direction of population mixing by means of a series of comparisons among size-frequency diagrams of euphausiid populations derived from the different localities in a given CalCOFI grid survey.

With literature now available, it is difficult to identify single larvae of most species of the Euphausiacea. As part of a project to provide identification and eventually a key to larvae of the California Current euphausiids, the larval development of *Euphausia gibboides* Ortmann, a major species of this current system, has been described and illustrated. The larvae of two very closely related species, *E. sanzoi* and *E. fallax* from southeast Asia and the Indian Ocean, are now being studied. The close relationship of the three species, determined on the basis of adult morphology, is substantiated by the study of the larval phases of their life histories. The fine details of larval morphology are now being analyzed with much interest as they appear to demonstrate unsuspected affinities within this group of species.

Krill Expedition, led by Dr. Brinton to South America on R/V *Agassiz* during May–September, 1974, studied the distribution of plankton in relation to the conspicuous oxygen minimum layer of the eastern tropical Pacific. *Euphausia mucronata*, the abundant krill of the Peru-Chile Current, and a biogeographical homologue of *E. pacifica*, was the object of a population analysis by Antezana, a Scripps graduate student from Chile. Numerous South American scientists participated in the cruise.

Study of southeast Asian euphausiids centers on South China Sea and eastern Indian Ocean material, particularly from Naga Expedition. Five new volumes of Naga reports are in press; they are concerned with physical oceanography of the area and plankton biology and taxonomy.

Drs. Abraham Fleminger and Kuni Hulsemann continued their investigations of the evolution and biogeography of planktonic copepods, concentrating on questions of range, habitat, speciation, and geographical variation on tropical to subtropical epipelagic calanoids belonging to the predaceous Pontellidae and the herbivorous Calanidae.

An analysis of geographical distribution relative to hydrography in

the Indian and Pacific oceans now in manuscript indicates that the habitat of the copepod *Pontellina* is equivalent to surface waters overlying the thermocline. Each species appears to be genetically adapted to migrate vertically only within the prevailing depth of regional surface water masses. It is proposed that the habitat and geographical range are determined by the semiclosed circulation of the surface water mass and the availability of suitable food within the depth range limits of the species.

Patterns of geographical distribution in American coastal zone zooplankton were examined by Drs. Fleminger and Hulsemann, and a comparative analysis of character divergence relative to geographical overlap was made of the indigenous species of *Labidocera*. The extent of morphological divergence in secondary sexual characters and in feeding appendages was estimated relative to geographical relationship among sets of sympatric and allopatric species. The results show strong positive selection for reproductive isolating mechanisms but little or no evidence of selection pressures affecting the morphology of feeding appendages or body size among co-occurring species.

In the tropical plankton, the ecologically important family of primary consumers, the Calanidae, is represented by the genus *Undinula*. As with its temperate-to-polar counterpart, *Calanus*, identification of the species of *Undinula* has persistently confused plankton workers. During their ongoing survey of integumental organs in the family Calanidae, Drs. Fleminger and Hulsemann found evidence that these morphological features could be used to unravel the taxonomy of *Undinula*, the key being the integumental organs of females located at body sites utilized by the male in mating and in spermatophore placement. The results show an interesting biogeographical pattern of two sets of sibling species varying in geographical contact and in extent of polytypy in females and adding support to the tropical-subtropical, biogeographical patterns in the oceans of the world, previously demonstrated by means of other genera.

The scanning electron microscope was used to explore various morphological features difficult to examine by conventional light microscopy and to develop a systematic collection of diagnostic illustrations of American copepods in the California Current. Initial results are very satisfactory, and as time permits, all of the common species of the region will be cataloged photographically. In addition to obtaining a remarkably informative permanent photographic record for analysis, the survey revealed a number of features of considerable systematic potential.

Dr. Lanna Cheng is studying some of the special adaptations of Halobates, the only pelagic marine insect, to its unique environment. These insects have a very efficient mechanical gill, the plastron, that enables them to breathe when accidentally submerged, for instance, during storms. In collaboration with Dr. Richard F. Lee, Skidaway Institute of Oceanography, Savannah, she has also investigated the lipids of these insects. They are able to store food in the form of triglycerides in much larger quantities than do their freshwater relatives, thereby enabling them to survive without food for two weeks.

Daniel M. Brown has developed four new systems for sampling marine organisms. One is a conversion of the Isaacs-Kidd mid-water trawl into an opening-closing net. Another is a closing, vertically towed net built to reduce the handling and "scarring" problems of this style of sampling. The third is a trap that can capture live fish at great depths, hold them in their own cold water, and keep them under pressure. The fourth is a low-cost, free-vehicle, drop-camera system developed to photograph schools of fish detected on sonar, thus providing a simplified method of identifying pelagic fish stocks.

North Pacific Central Gyre Studies

Under the direction of Dr. John A. McGowan, several studies are being conducted in the North Pacific Central Gyre. A historical review of the scientific information about the hydrography, population, and community biology and fisheries of the area (25–35°N, 145–160°W) is nearly completed.

Until 1968 very few studies were devoted specifically to attempts to understand processes and events taking place within the gyre itself, and the gyre was thought of as being a rather homogeneous environment with clear, warm water; a deep, permanent thermocline, and very low standing crops of phytoplankton, zooplankton, and fishes. The only controversial aspect of this area concerned the assertion of Sverdrup, Johnson, and Fleming (*The Oceans*) in 1942 that there was actually a

double, anti-cyclonic, circulation system in the area.

In the last decade, it has become apparent that much of the weather (and to some degree, climate) is strongly influenced by air-sea interaction; and because the North Pacific Central Gyre is so large and shows such pronounced long-term but migrating surface temperature anomalies, the gyre is thought to be very important. The central gyre best approximates a closed biological system, an essential assumption in ecosystem theory. The fisheries potential, although small on a unit area basis, is fairly large because of the large total area. For example, the commercial fisheries catch from the area (25–35°N, 145–160°W) has been tabulated by species for the years 1967–71. These are tuna, swordfish, marlin, and skipjack (nine species total). The value of this catch (at 1973 prices) was \$7,356,062.

The large, vertically stable, low-productivity, central gyre has boundary zones that are much less vertically stable than the gyre itself. The exact location of the boundary zones is not, however, well documented. There is physical and biological evidence from the upper few hundred meters that the northern boundary, whose axis is centered about 40°N, fluctuates latitudinally and may reach as far south as 37°N. Thus, this zone of increased vertical mixing may be rather close to the locales being studied. There is new evidence for a double gyre system in the central North Pacific. This evidence is biological, physical, and theoretical. If so, then the meridional boundary zone between the two gyres (with a main axis about 170°W) could be an area of enhanced vertical mixing.

The initial field program in the North Pacific Central Gyre concluded with six expeditions to the vicinity of 28°N 155°W. These completed the series of samples for seasonal coverage and provided opportunity for special projects. Dr. Elizabeth L. Venrick is examining the phytoplankton samples for differences in the composition and seasonal development of the deep, shade-adapted layer, which characteristically occurs during the summer at 120 m, and the very distinct, low-nutrient populations that occur at shallower depths.

These observations have been supplemented by concurrent studies on phytoplankton dynamics conducted by the Food Chain Research Group (FCRG) in the Institute of Marine Resources. Analysis of nine years of field data on the distribution of the nitrogen-fixing, blue-green, alga *Richelia intracellularis*, in the North Pacific, was concluded. There is strong evidence that this may represent a significant source of new nitrogen for the euphotic layer, at least on a local scale, and blooms of *Richelia* are correlated with increases in phytoplankton standing stock and productivity in the upper 60 m.

Present studies led by Dr. McGowan in collaboration with members of the FCRG include the distributions of chlorophyll-*a*, primary productivity, and zooplankton standing crop.

Chlorophyll-*a* is a very good measure of the standing crop of plants. Variations in plant standing crop, in time and space, are an integral part of the ecological dynamics of the system and in a nutrient-limited situation, they can provide clues as to the input of deeper, nutrient-rich water in the recent past. A very large set of chlorophyll-*a* data from the central gyre has been processed and is being analyzed. One outstanding result is the discovery of the deep chlorophyll maximum at 110–120 m.

Variations in plant growth where light is adequate for photosynthesis are directly related to the rates of input of inorganic compounds of nitrogen and phosphorus. The outstanding feature of the central gyre is that the rate of input of nutrients to the upper zone (<150 m) appears to be inadequate to support the observed rate of photosynthesis. Apparently vertical mixing in this area is not yet understood.

A phosphate trial-balance sheet that includes uptake by phytoplankton, recycling by zooplankton, and vertical eddy diffusivity does not balance. One implication is that there is more vertical and/or horizontal mixing of nutrient-rich water into the area than can be accounted for with orthodox knowledge. There are strong reasons to believe that it is vertical mixing rather than horizontal mixing. Perhaps vertically migrating creatures also transport significant nutrients.

The primary productivity (photosynthetic rate) is an instantaneous measurement of rate that depends on nutrient input, light, and the history of the plant population. A most interesting result is that the summer of 1969 had *twice* the productivity rate of previous or subsequent summers. Apparently some significant mixing event was taking place or had taken place the previous spring or winter.

The zooplankton standing crop is a mixture of herbivores and first-stage carnivores. Their abundance is strongly dependent on the immediate and previous productivity regime. Because of their slow turnover

rate (weeks to months), however, they tend to integrate, over time, the productivity dynamics. The major reason for this, other than their length of life, is that they tend, by their excretory processes, to recycle nitrogen and phosphorus compounds, thus increasing the residence time of these nutrients. In accord with the productivity data, the standing crop of zooplankton in the summer of 1969 was *twice* that of previous or subsequent summers, thus indicating a greater than usual upward mixing of deeper, nutrient-rich water sometime in the previous few months.

Data have been obtained on two size-categories of actively swimming nekton, the 1–15 cm fish and the much larger commercial fish of the area. The smaller fish are mostly mesopelagic that live at depths of more than 300 m during the day and migrate to or near the surface at night. These migrators are the major predators on the zooplankton and are thus an important part of the system. Along with the diurnally vertically migrating zooplankton, they could serve as an active vertical transport vehicle for nutrients and other substances, such as radioactive compounds.

A very large number of hydrographic measurements exists in the central gyre data set. These have been only partly processed. Most of them cover depth ranges of 0–700 m, but a substantial number go to 2,000 m and a few to the bottom. Temperature curves from 1969 indicate an unusual hydrographic event.

Anaerobic Sediment Investigations

The study of marine sediments is a means of extending the historical perspective of oceanic events. Sediment provides access to material characteristic of past times, and because of the effective horizontal dispersion of sediment particulates, the material itself is also characteristic of broad areas.

Marine anaerobic sediments are particularly valuable in that they can be resolved on time intervals approaching one year. Thus by using various techniques, including box-coring methods that consistently obtain the present sediment surface, verification of sediment surface recovery by the presence of excess Th-228, and stratigraphic dating by varve and Pb-210 chronology, Isaacs, Andrew Soutar, Dr. Stanley A. Kling, and Peter A. Crill have been able to perform detailed historical studies.

In the Santa Barbara, Santa Monica, and San Pedro basins, these studies include such elements as common lead and its isotopic ratios, mercury, and a suite of metals. Many substances show a systematic increase in concentration during the past few decades, and record the magnitude of man's effect on the geochemical balance in the coastal sea off California.

A detailed investigation of fish debris in the sediments of the Santa Barbara and the Soledad basins has provided insight into the historical abundance of pelagic fish off the California coast. Correlation between fish populations as determined by fishery statistics and fish-scale deposition in sediments has shown that the interpretation of past abundance levels is probably reliable. The historical perspective suggests the past 30 years have been characterized by considerably high levels of anchovies, and that the sardine passed through a protracted period of low abundance in the last part of the 19th century, as it had during a number of other occasions during the last 15 centuries.

Soutar and Dr. Kling are developing their investigations to include climatological and ecological factors in the sea off California and in other areas, such as the Gulf of California and coastal Peru.

Marine Physical Laboratory

The Marine Physical Laboratory's (MPL) activities continue to be directed toward understanding problems related to the generation, propagation, and detection of acoustic energy in the ocean and surrounding media. This involves interaction of diverse facets of marine physics and ocean technology. It is possible to divide the work for descriptive purposes into four major areas of study: oceanic acoustic environment, sea-floor properties, signal processing, and ocean technology.

In addition to research in these four areas, a considerable effort is expended in assuring (largely through participation in advisory committees and study groups) that new ideas are passed along to others who may be able to utilize them. For example, the senior members of the

staff spent approximately one-and-a-half man-years in advising, and in short-duration committee meetings and symposia for the benefit of federal agencies and scientific societies, including the National Academy of Sciences, National Academy of Engineers, National Science Foundation, U. S. Atomic Energy Commission, UNESCO, U. S. Navy, National Council on Marine Resources and Engineering Development, Acoustical Society of America, and the American Geophysical Union.

During the year, Dr. Robert McDonough, on sabbatical from the Department of Electrical Engineering of the University of Delaware, worked on various aspects of signal processing, including theoretical work on non-linear, long-aperture, parametric receiving arrays, maximum-entropy spatial processing of array data, and deconvolution processing for a non-uniform array. Dr. McDonough's work here was a continuation of a program in which visiting scientists interact with the scientific staff at MPL, Scripps, and UCSD.

Dr. Victor C. Anderson, associate director of MPL, had additional responsibilities this year as Chairman of UCSD's Department of Applied Physics and Information Sciences.

Under the guidance of Dr. Fred N. Spiess, MPL has enlarged its continuing study of internal wave motions in the upper layers of the deep sea. The objectives are to better measure the distribution of internal wave energy with respect to horizontal wavelength, vertical wavelength, and frequency, and to observe the interaction of the wave field with the upper ocean environment. The approach taken in this work, conducted by Robert Pinkel for his PhD thesis, is to repeatedly measure profiles of temperature vs. depth in the top 440 m of the sea at three horizontal locations surrounding the research platform FLIP. Internal-wave vertical displacement is inferred from the time variation of the profiles. Month-long FLIP operations off the California coast in November, 1972, and June, 1973, and a central ocean study off Hawaii in November, 1973, have provided a large amount of new internal-wave information. Surprisingly large energy levels in low-frequency, short-vertical wavelength motions were observed, together with an absence of such energy at high frequency.

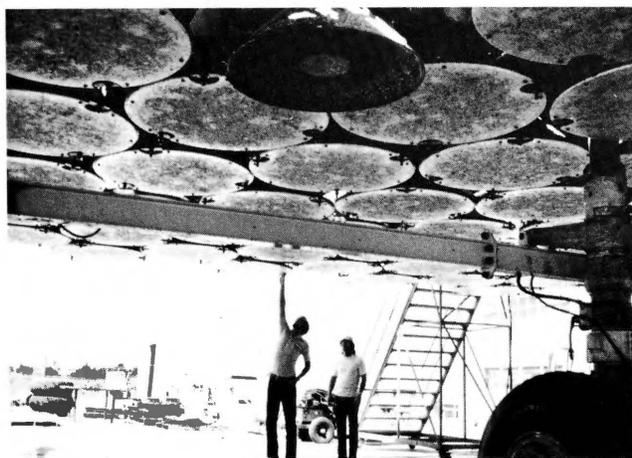
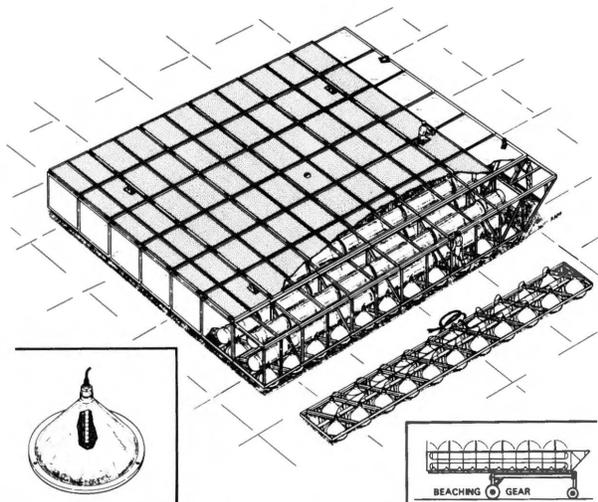
It is planned to add electrical conductivity measurements to the current profiling capability, as well as a slower profiling system to measure horizontal currents. An acoustic doppler reverberation system is currently under development. This will provide measurement of horizontal motion of the water in a narrow beam stretching several hundred meters out from FLIP.

Under Dr. Anderson's initiative, the effects and extent of layered inhomogeneities in the ocean will be measured acoustically with a large 15m × 15m array containing 128 hydrophones. An 8kW sound source is located in the center of the array facing downward. This unique array will distinguish between coherent and incoherent acoustic signals back-scattered from layered and discrete scatterers. The 58,500-kg array, when in operation at sea, will be suspended at a depth of 30 m by nylon ropes from R/P ORB, and when in transit will be towed at the surface behind ORB. It is believed that this is the largest array of its type to be developed and successfully tested at sea.

Dr. Gerald B. Morris' group has been conducting a series of measurements of the coherence, attenuation, and variability of long-range signal propagation and of the vertical distribution of ambient noise as a function of depth utilizing vertical arrays suspended from FLIP while she is moored in the deep ocean. These measurements are fundamental to understanding how different oceanographic regions affect sound propagation.

Dr. Hugo E. Bezdek completed his measurements of sound attenuation as a function of depth in the 30–50 kHz region with measurements in the Sulu Sea to complement the results obtained in the eastern Pacific. These have been conducted to establish the validity of predictions based only on limited laboratory work and to understand what is responsible for the observed pressure dependence. In conjunction with this work, he also studied high-frequency backscattering from the ocean floor as a way to establish surface roughness.

Dr. Fred H. Fisher's group completed an extensive set of measurements to understand how variations in the ocean and its interface produce acoustic fluctuations in surface-duct and bottom-bounce propagation paths in the Hawaiian area during the Mai Hai II cruise. Work is continuing on the development of a pencil beam (1°), 90-kHz, precision echo sounder to be mounted on the bottom of FLIP so that by scanning ± 10° in orthogonal directions, bottom topography variations can be measured in order to relate them to the observed acoustic fluctuations. Initial measurements of acoustic pulse structure have been



Investigation of layered homogeneities by Marine Physical Laboratory (MPL) staff members extended reverberation studies designed to observe sound scattering from fine-scale, layered structures of temperature and salinity gradients in order to determine the horizontal extent and temporal behavior of these structures.

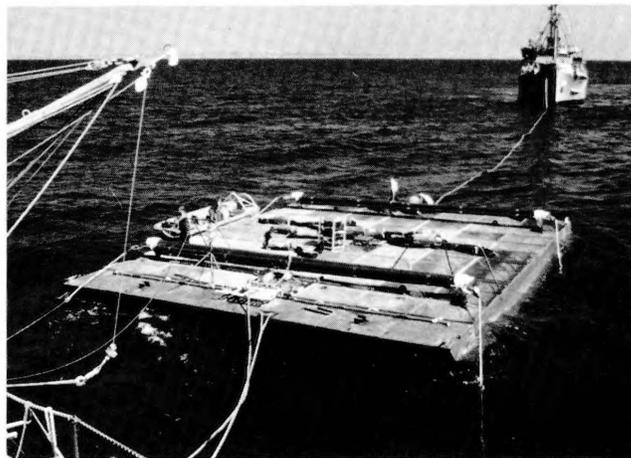
The investigations involved a 58,500-kg, acoustic array measuring 13.5 m square and 1.8 m high and incorporating 128 downward-looking hydrophones in conical reflectors; the array's handling equipment; and its signal-processing electronics. MPL engineering, scientific, and shop staffs designed and fabricated not only the array but also its launch-and-recovery equipment (the latter utilizing surplus, Navy, aircraft-landing gear).

Sketch at upper left indicates position of the reflectors, one of which (left inset) is shown with its cable extending through the top. More than 11 m of

made with a 500-m, 20-element, vertical array as a function of range in order to understand how variations in the ocean affect long-range propagation. Vernon P. Simmons is completing his PhD studies in the laboratory on the low-frequency (1 kHz) acoustic relaxation effect in the ocean. By using the resonator technique with 12-, 50-, and 200-liter spheres filled with seawater and suspended in a vacuum, he has found that the boric-acid, controlled relaxation caused an increase in absorption by a factor of ten over the predicted value.

Dr. Fisher's studies of electrical conductance of aqueous solutions of salts related to sound absorption in seawater have yielded a new dissociation constant for sodium sulfate, lower by a factor of more than two than the conventional value.

Dr. Leonard N. Liebermann and Stan H. Lai have been studying extremely low-frequency (below 30 Hz) underwater sounds, termed "infrasound." Infrasound can be generated by large marine animals or by the rotating blades of a large ship's propeller. At a typical frequency of 5 Hz, the infrasonic wavelength is 300 m, which is comparable to the



cable are required to feed data from reflectors up through water column to instrumentation aboard array's mother ship, R/P ORB. Photo's right inset shows array on beaching gear used for land mobility (upper right photo). To one standing beneath array, conical reflectors appear as in lower left photo.

Lower right photo shows M/V Gear towing array and ORB during operational test off San Diego. Array is attached to ORB (barely visible at lower left) by four handling ropes. When it is time for array to slip beneath sea surface, ballast and buoyancy tanks are activated and array submerges below ORB. Gear's tow rope maintains the tension needed to steady array as winches on ORB slowly lower it. In its operational mode, array stays level to within plus-or-minus half a degree.

Marine Physical Laboratory

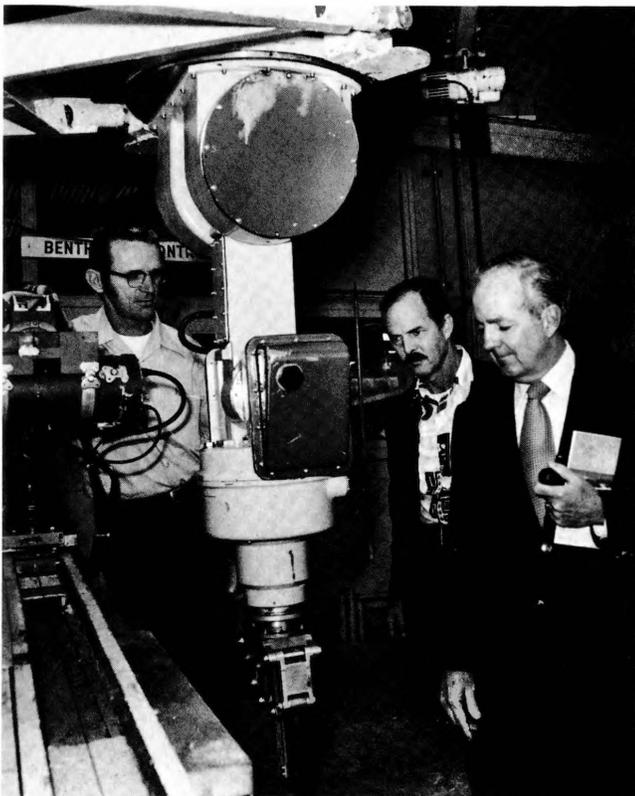
bottom depth in shallow coastal waters. Under these unusual propagation conditions, it is questionable whether infrasonics can propagate well and can be received by means of conventional hydrophones. Studies thus far indicate excellent reception in spite of shallow water, with almost continuous reception of signals from nearby and over-the-horizon shipping. Infrasonic reception was found to be critically dependent upon devising new techniques for isolating the hydrophone and its cable from surface-wave motion. In conjunction with the shallow water research, Dr. George G. Shor, Jr., and William Whitney are readying an experiment to measure arrival angle structure and other aspects of infrasonic sound-wave propagation in the deep ocean.

Sea-floor studies conducted by Drs. Spiess, John D. Mudie, and Carl D. Lowenstein utilizing the Deep-Tow instrument have encompassed many different regions and research areas. This research leads to new requirements for measurement techniques; for example, digital signal processing techniques have been applied to the side-looking sonar in order to obtain quantitative measurements of sea-floor backscattering



Technician checks calibration of a Salinity/Temperature/Depth instrument in new Mallory precision test bath installed at San Diego-based Southwest Regional Calibration Center (SRCC) of the National Oceanographic Instrumentation Center, Washington, D.C. SRCC is operated by Marine Physical Laboratory for National Oceanic and Atmospheric Administration. Bath is used to check instrument to assure it meets rigid specifications required for its operation.

Marine Physical Laboratory



Inspecting tractor-like RUM (Remote Underwater Manipulator) are Rear Adm. Merton D. Van Orden, USN, Chief of Naval Research, Washington, D.C., at right; Associate Director Shor, center; and Gerald L. Denny, electronics technician. Admiral Van Orden was on campus conferring with Director Nierenberg and other faculty and staff members. In foreground is the manipulator, or working arm, of RUM, which was designed and developed by Scripps's Marine Physical Laboratory for work on the sea floor.

at high frequencies (100–200 kHz). These data, in combination with other deep-tow observations of fine-scale aspects of the sea floor, will help man to understand how the physical characteristics of the ocean bottom affect sound propagation in its vicinity.

The sea-floor studies group also has a large number of graduate students whose work includes (1) sea-floor geomorphology, sedimentary processes, bedforms, and bottom currents (Peter Lonsdale); (2) sea-bottom magnetics and their relation to surface magnetics, sea-floor spreading and ocean-ridge formation, and the geomagnetic time scale (Kim Klitgord); (3) fine-scale, ocean-floor reflectivity and attenuation of low-frequency (4 kHz) signals (Robert Tyce); (4) structure, sedimentation, and near-bottom observations of the Carnegie Ridge near Peru (Bruce Malfait); (5) sedimentary processes and near-bottom observation of the Blake-Bahama Outer Ridge (Roger Flood); (6) geology and physical properties of sediments and the history of carbonate sequences in the equatorial Pacific (Larry Mayer); (7) near-bottom geothermal measurements (Kathy Crane); (8) near-bottom organisms collected by net towing from the Deep Tow, the first time it has been possible to collect such samples (Karen Wishner); and (9) fine-scale geology of the Mid-Atlantic Ridge and associated transform faults (Ken Macdonald). The first four students have received, or are about to receive, their PhD degrees.

Heat-flow studies aimed at determining plate-tectonic history in the Andaman Sea were conducted by Larry Lawver under Victor Vacquier's direction on Legs 6 and 7 of the Tasaday Expedition. On Leg 7, heat-flow results in the Sulu Sea, Philippine Sea, and the Parece Vela Basin were combined with previous results from Antipode Expedition to show the effect of local environment on heat-flow results in areas of the same geological age. It was found that local sediment cover could reduce heat flow significantly.

Dr. Roger N. Anderson continued with his sea-floor studies of geothermal heat flow on the Tasaday Expedition to the Mariana Basin.

In the area of signal processing, Dr. Anderson's group extended its past experience in multibeam, adaptive, digital beamforming to new areas in which variations in the sound-velocity profile and array geometry can be included to provide on-line compensation for these effects. Work is also in progress to develop an imaging sonar with a three-dimensional display for use in cloudy water produced, for example, in soft-bottom sediments stirred up by sea-floor work. Another project in design stage is a large-scale, passive, multibeam billboard array that will increase resolution in both the vertical and horizontal. This will contain 750 elements to form 1,000 simultaneous beams. New electronics for vertical hydrophone arrays are being designed by Robert W. Cherry and Dr. Anderson to be deployed off the mooring lines of FLIP, so that the horizontal and vertical direction and coherence of acoustic signals can be measured simultaneously. Work on Sic Transit Sonitus, a project (initially under the late F. V. Hunt's direction) to study effects of ambient noise levels of passing ships, is continuing with Richard A. Harriss.

A new reverberation system is being designed to measure the horizontal and vertical distribution of scatterers in the water column. Whereas earlier work included the frequency range from 4 to 25 kHz, the new system will go from 20 to 400 kHz, and will include a new feature, azimuthal scanning, that will permit resolution of the horizontal variability of scattering organisms.

Dr. Robert A. Rasmussen completed studies of the effects of sound scattering and enclosures on the frequency response and directionality of hydrophones mounted in axisymmetric bodies containing resonant structures. Even in the absence of an enclosure, severe distortions in frequency response curves and directivity patterns were observed, particularly at frequencies for which the product of the wave number and body dimension exceed 0.1 and those corresponding to resonant vibration of the body assembly. Enclosure of the hydrophones by an acoustically transparent conical shell resulted in further distortions of the frequency response and directivity and increased hydrophone sensitivity to internally generated vibrations. A high degree of correlation was found among outputs from accelerometers mounted interior to the body and the externally suspended hydrophones at pronounced mechanical resonances. Comparisons of hydrophone and accelerometer responses to internally and externally generated signals, however, indicated that cancellation of hydrophone responses to the former is possible only at discrete frequencies.

With Dewitt O. Efrid as officer-in-charge, R/P FLIP was used for eight expeditions in the Pacific, including two in the Hawaiian area,

mostly for acoustical studies and one for air-sea interaction studies as a part of the NORPAX program, reported elsewhere in this section.

With Terry G. Hoopes acting as officer-in-charge, ORB (Oceanographic Research Buoy) served as the surface-support platform for a variety of undersea research projects. Eight operations were carried out requiring 94 days at sea. Five of the operations totaling 54 days were in support of remote sea-floor work experiments utilizing the RUM vehicle (see "RUM" below). Two operations, one for 12 days, the other for 24 days, supported joint Naval Undersea Center-MPL underwater acoustics experiments. Handling tests for a large acoustic array, to be deployed from ORB for sound-scattering measurements in the MPL Scattering Studies Program, were carried out during the final four days of operation.

Under the direction of Dan K. Gibson, RUM (Remote Underwater Manipulator), operating from R/PORB, was used to perform a variety of work at seven sites on the sea floor. The work sites ranged in depth from 150 to 1,255 m.

Work included a cooperative trafficability study involving Lockheed Ocean Laboratory and MPL, the initial sea test of a rock drill designed and fabricated specifically for use on the RUM vehicle; recovery, repair, and reinstallation of a sea-floor-mounted sensor array, some high-resolution sonar experiments, and an intensive benthic biological study. Graduate research assistant, Charles M. Alexander, has been recording and analyzing detailed work-time statistics related to the performance of this remote work system and will publish a report dealing with the work effectiveness and economics of such a system. The Benthic Biological Study (Quagmire Expedition) was performed under the direction of Dr. Robert R. Hessler and a team of biological researchers on board ORB. RUM's unique capability for remote manipulation, observation, and precision navigation, and its stability on the bottom, payload, and endurance, made possible a sustained level of detailed benthic observation and sampling never before achieved in the deep sea. A total of 190 hours of actual work time on or near the bottom was logged during this 29-day operation. This work is briefly described under the Marine Biology Research Division section elsewhere in this report.

During the past year, the calibration facility operated by MPL under contract with National Oceanic and Atmospheric Administration's (NOAA) National Oceanographic Instrumentation Center progressed in both proficiency and equipment capability. It has been involved in the calibration of oceanographic instrumentation for governmental and non-governmental research, concentrating for the most part on STD (CTD) equipment, mechanical bathythermographs, and laboratory salinometers. A seawater storage-and-transportation system has been installed, and in addition, a medium-sized, 1,000-psi pressure tank, an environmental test chamber, and a rapid-temperature-response, Mallory calibration bath controlled to 0.001°C. A partial installation has been completed of the large, high-pressure-, temperature-, and salinity-controlled nonmetallic tank. New equipment designs are in progress for making definitive measurements of sound velocity in seawater as a function of temperature, pressure, and salinity in order to resolve discrepancies in the literature. The large pressure tank will facilitate such work. High standards of calibration have been maintained, and all of the critical instruments used are periodically checked by a measurement standards laboratory providing traceability to the National Bureau of Standards.

In order to pursue the various research projects outlined above, substantial efforts in ocean engineering have been required on the part of the engineering, scientific, and shop staffs. As an example of such an effort, in order to transport the 58,500-kg scattering array from land to water, it was necessary to design and fabricate a means of launching and recovering the array using surplus Navy aircraft landing gear. For the array to function properly, a design constraint was that the hydrophones had to be aligned to within 2 mm across the entire 30-m x 30-m aperture on land and remain in alignment after launching. This constraint required considerable ingenuity on the part of the shop and technical staff. Modifications to other equipment and platforms, Deep-Tow, FLIP, ORB, and RUM are being made continually in order to improve their at-sea capabilities.

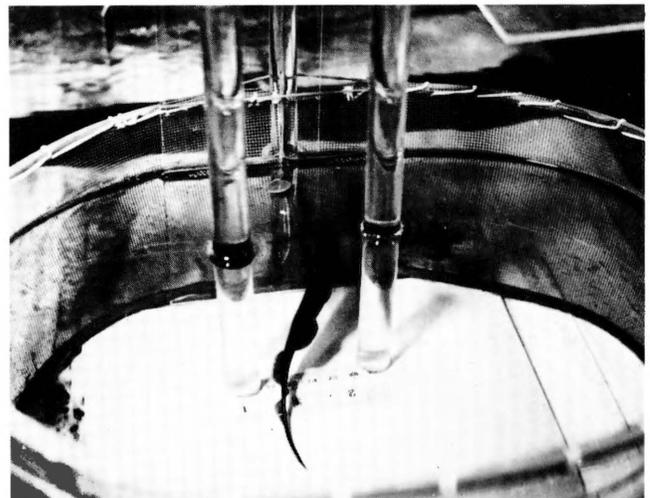
Neurobiology Unit

Drs. Theodore H. Bullock and Christopher J. Platt of UC-Berkeley completed the first study in elasmobranchs of brain activity evoked by feeble, direct-current, electric signals in the water. The principal animals employed were *Torpedo*, the electric ray, and *Scylliorhinus*, a common shark. By recording activity evoked by other sense organs, such as the eye, it was found that the exquisitely sensitive, specialized electroreceptors, called ampullae of Lorenzini, deliver their signals of excitation to the same part of the midbrain as the eye, the optic lobe. The dynamics of the two kinds of response are quite different, however, and sharks are quicker in processing such information than rays. In asking how electric rays avoid electrocuting themselves, the scientists discovered several kinds of animals that are extremely resistant to electroshock without showing convulsions. This may be a lead of medical significance.

Dr. Adrianus J. Kalmijn and collaborators, Rebecca and Patricia Bernal, patiently trained sharks in the unique fiberglass tanks of the Experimental Behavior Facility designed to restrict access by electrical, magnetic, vibratory, and light stimuli. The experiments gave clear evidence that sharks can orient in respect to very weak homogeneous direct-current fields similar to those that occur in large ocean streams, such as the Gulf Stream. In addition, as they swim through them, they can detect and orient to magnetic fields weaker than the earth's. Comparable experiments with certain fresh-water teleost fish revealed the same abilities that were expected, because the species chosen have equivalent electroreceptors specialized for direct and very slowly changing electric voltage gradients in the water. These are Amazonian, weakly electric-knife fishes.

Dr. Joseph Bastian discovered new evidence that the cerebellum in fish is specialized for processing information about the position of the body relative to objects and spaces around it, that is, for analysis of sensory input, whether or not there is motor performance under way. The unusually well developed cerebellum of electric fish has Purkinje cells sensitive in a small receptive field to movement and direction of movement of objects. Some respond best, not when the object is closest to the fish, but at a small distance. Such cells are quite insensitive to the social communication signals, involving fine frequency resolution, such as those that elicit the jamming avoidance response. This input is analyzed with high, wave-form discrimination in midbrain nerve cells that do not care about object location.

Dr. David G. Lange and collaborators, Drs. Peter H. Hartline and Ann C. Hurley, extended their study of vision in octopus and squid by electrophysiological recording of single and multiple unit activity in the optic nerves and optic lobe of the brain. Shore and sea-going computers are utilized in this research.



In a Neurobiology Unit investigation, the African electric fish, *Gymnarchus*, "electrolocates" objects, such as plexiglas rods, and follows their motions.

Neurobiology Unit

Dr. Walter F. Heiligenberg found a "blind" and a sensitive period in electric fish of species that emit a millisecond electric pulse every 20 ms. or so in their receptivity to a foreign pulse that might contain information but at certain moments might "jam" the fish's sampling of the world via his own pulse field. The jamming is quantitatively assayed by the fish's performance in hovering between swinging obstacles. With Dr. Bullock, he also recorded the jamming avoidance response of *Gymnarchus*, an African electric fish that has evolved this special behavior pattern quite independently of the South American gymnotids, and has been studied at Scripps.

NORPAX

An understanding of the phenomenological description of the many large-scale ocean and atmosphere interactions is needed before reliable long-range weather and climate forecasting can become possible. Present data show that the ocean has distinctive, large-scale, sea-surface-temperature (SST) anomalies. The close connection between these anomalies and similar disruptions in the atmosphere suggests that the sea serves as a sluggish energy source for the atmosphere that can effect atmospheric-flow patterns, thus providing a possible explanation of "anomalous weather." The NORPAX (North Pacific Experiment) program is designed to study these phenomena.

A major NORPAX contribution during 1973-74 was the planning and execution of a coordinated experiment that took place during January-February, 1974, in the North Pacific Ocean, 1,440 km north of Hawaii. This experiment was the first in a series of experiments that will eventually culminate in a heat-budget study aimed at determining the mechanics of SST anomaly generation. Last year's work had the modest goals of determining the principal space/time scales of atmospheric-flow patterns and sea-surface-temperature patterns.

Observations were conducted from Scripps's research ship, *Thomas Washington*; from the Institution's manned spar buoy, FLIP; and from a Navy aircraft. A large, unmanned buoy, ALPHA, and over-the-horizon (OTH) radar and satellites provided additional data. The experiment was named POLE, to indicate that these initial studies would be concentrated in a relatively small area, but extend vertically through the layers of the ocean which immediately affect the atmosphere.

The weather experienced during POLE was relatively mild for the central Pacific in the wintertime. Typical winds of 15 to 20 knots occurred over much of the time with some periods of calm and fog. Highest winds, up to 35 knots, occurred during the last week of the experiment. Immediately prior to the experiment, a large storm had existed in the region for approximately two weeks. Just after the experiment, another very large storm came into the region. Thus, the ocean that was viewed during POLE was "relaxing" from the first storm situation.

Numerous salinity-temperature-depth (STD) casts from FLIP were made at very close time intervals. The first results showed a rapid time variability in the density field at FLIP.

The *Thomas Washington* conducted an intensive STD and expendable bathythermograph (XBT) survey in the region within 100 km of FLIP. Highly complex temperature and salinity fields were encountered, and numerous small fronts were apparent. Within the "mixed layer" there seemed to be two, sometimes three, layers in the temperature field, although the salinity adjusted itself in a way that each of the layers within the overall mixed layer had almost the same density.

Various hydrographic measurements were made from the ship. Particular attention was paid to the small-scale (10 km) lateral variations of temperature, salinity, and density found throughout the mixed layer. This layer is more homogeneous, both laterally and vertically, in density than in temperature or salinity separately, and the dominant process seems to be a quasihorizontal interleaving of small water masses rather than a local vertical stirring driven by the wind. As a necessary prerequisite to future studies of this kind, work is now being done to modify and improve computer-based routines for acquisition and analysis of STD data on Scripps ships.

AXBT measurements taken within ± 500 km of FLIP from a NAV-OCEANO P-3 aircraft indicated a strong north-south gradient in the oceanic temperature field. There was no gradient to speak of in the east-west direction. Typical RMS (Root Mean Square) displacements for isotherm depths were of the order of 20 m. Numerous horizontal profiles of sea-surface temperature were obtained with an airborne radi-

ation thermometer. Characteristic scales of temperature variability were on the order of 200 km. Satellite estimates of SST showed a good relation with aircraft observations when averaged over monthly time scales and 2° latitude squares.

The aircraft was also used to track 30 freely drifting buoys deployed in the vicinity of FLIP and tethered to drogues at 30 m. During the three-week period the mean drift of all buoys combined was essentially to the north at 3 cm/sec. Individual buoy tracks indicate the scales of current motion in the region were large compared to that of the mean buoy cluster. Isotropy was not observed in the flow field. This research demonstrated the complexity of normal oceanic flow and the need of the large numbers of drift measurements required to specify oceanic upper layer flow.

Other buoys were remotely tracked with OTH radar. Five of the six buoys were probably located on the first day; but after that only two could be found. After one month one was still operating. The last buoy continued working for more than four months. These longer-term trajectories indicate eastward flow as expected, but the motion was not uniform with time.

The measurement of air/sea fluxes from FLIP was conducted with no major difficulties, although the flux situation during a heavy weather condition was not measured because of the absence of storms. The data, nonetheless, will be of exceptional utility. A number of fundamentally different flux regimes apparently existed during the course of the experiment. A verification of the flux estimated from the bulk formulas versus those measured by the eddy correlation technique should prove invaluable for future NORPAX work. It was found that the major flux was caused by the latent heating term, and that sensible heating over the 20-day measurement period averaged to virtually zero.

Repeated vertical sections of currents were taken from FLIP with ducted current meters. A 20-day time series of upper-ocean velocity profiles was obtained, using a Scripps-designed current meter that was operated from FLIP. These sections revealed a high degree of variability in the current field. The results indicated that the upper 130 m moved as a slab essentially in the direction of the local wind within the frequency band of 1/3 to 3 cpd (cycles per day). No explanation has been found for this puzzling result. Only occasionally is there a suggestion of an Ekman layer.

The attempts to infer surface wind, current, and waves from OTH radar were successful insofar as a large amount of data were gathered with which to check the feasibility of this remote sensing technique. It appears feasible to measure wind direction remotely to within $\pm 20^\circ$, although the ability of OTH radar to measure wind speed with reasonable accuracy is in doubt. Ionospheric interference appears to preclude use of OTH radar for measuring surface currents.

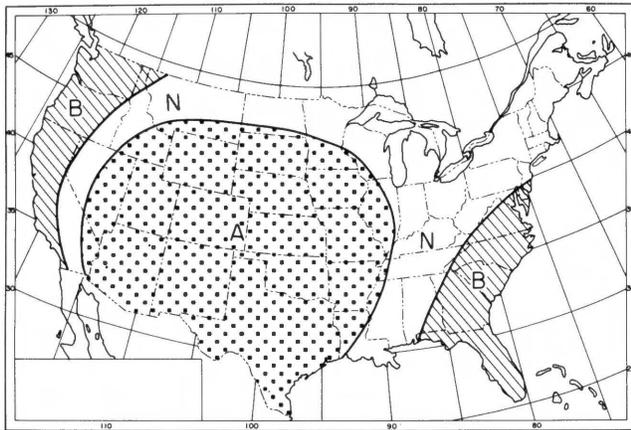
The ALPHA buoy performance was less than required. Two profiling ocean sensors failed quickly. Several meteorological sensor failures were also encountered. Finally, a data processing unit failed, and data transmission was terminated.

Other components of NORPAX produced major results during the past year. Some of these are listed below. An interesting feature in the North Pacific Ocean was revealed by the climatological mean sea-surface temperatures shown in the accompanying figure. On the average there appears to be a large-scale but small-amplitude, zonal variation in surface temperature at mid-latitudes in the central and eastern North Pacific. The east-west dimension of the temperature variation is on the order of 1000's of km and the amplitude is on the order of 1°C . This temperature variation appears on the average during all months of the year, but changes slightly from month to month. It is hypothesized that the temperature variation is related to advection of heat by circulation in the North Pacific and is caused by the driving force of the wind. This hypothesis is being tested through an analysis of existing data and through the construction of mathematical models.

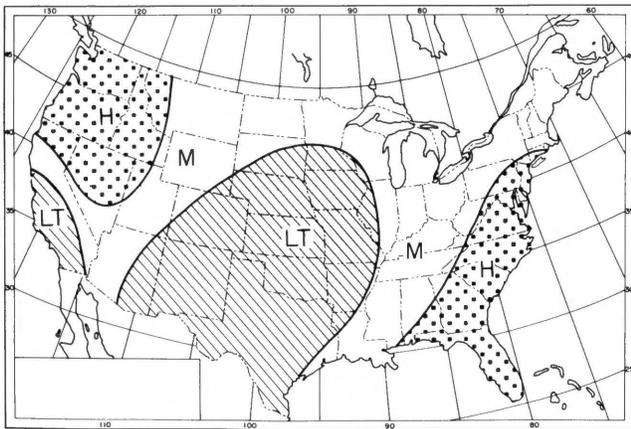
During the last year new sets of specification equations have been derived involving sea-surface temperature and 700 mb height patterns for all seasons, using 25 years of data. Hindcasts made from these equations generally have a reasonable high skill level. The experimental forecasts for winter 1973-74, and summer 1974, are encouraging (see illustrations). Most of the instabilities in the specifications have been traced to "noise" in the SST data fields. Consequently, it has been decided to analyze the data fields through the use of empirical orthogonal functions with the aim of smoothing the SST fields to our scale of interest.

It has been shown that a change in an upper level trade wind index

PREDICTED FOR SUMMER (JUN., JUL., AUG.) 1974
TEMPERATURE



PRECIPITATION



Completed June 6, 1974 from data ending May 28, 1974

Charts show forecast for temperature anomalies (Above, Below, and Near normal) and precipitation classes (Light, Moderate, and Heavy) for summer of 1974.

Dr. Jerome Namias

leads in time to changes in strength of the Equatorial Countercurrent, which, in turn, leads to the onset of the El Niño. Analysis of the seasonal pattern correlations between SST and 1000-700 mb thickness over the eastern North Pacific suggests a strong influence of air mass modification by air advection over water masses of different temperatures and points to varying atmospheric stability as a principal component of large-scale heat exchange. Correlation fields of stability anomaly contain large coherent areas which appear to be related to coastal air pollution in southern California.

Examinations were conducted of time and space scales of surface and sub-surface temperature fluctuations using data from the NOR-PAX and Trade Winds Expeditions, as well as ship-of-opportunity data. The near-surface layer is characterized by very large spatial scales, whereas the region below the mixed layer is regulated by smaller, MODE-type eddies. The time scales of the upper layer appear to be much more rapid.

A spectral and cross-spectral analysis of most of the time histories of sea-surface temperature obtained by Scripps and General Dynamics buoys in the Pacific has been completed. One aspect of the study that has contributed to the determination of oceanic noise levels has been the characterization of the space scales associated with the wave form and energy field of the 12-hour internal oscillation. The wave forms



Chart shows 20-year average of the monthly mean sea surface temperatures for five degree squares centered on 40° North latitude in North Pacific Ocean plotted against longitude. There is one curve for each month of the year. Absolute temperatures are not given, but relative scale indicated by the 1°-C interval is the same for all curves.

Dr. Kern E. Kenyon

were found to be spatially coherent over separations of the order of 5 km, but not coherent in the range of separations at 50 km. The energy in the wave form (as characterized by the mean square temperature) was incoherent at separations of 5 km in the horizontal and 50 m in the vertical. The incoherency is thought to be caused by microstructure.

A multilayer simulation model of the North Pacific Ocean has been developed, and with it the overall mean state, both diagnostically and prognostically, of all major parameters, such as temperature, salinity, and velocity distribution in the entire North Pacific Basin, has been obtained. The model is now in an advanced operational stage, flexible in dimensional change and efficient in execution. It is now running, with much finer grids of 10 layers, at the National Center for Atmospheric Research, for time-dependent mean state and carrying out oceanic anomaly experiments based on realistic atmospheric and oceanic observational data for the understanding of the evolution and fluctuation of thermal anomalies and their related energy transformation processes in the North Pacific Ocean.

Ocean Research Division

The multifaceted Ocean Research Division encompasses research projects in the fields of biological oceanography, marine chemistry and geochemistry, geophysics, and physical oceanography.

Dr. D. John Faulkner has been carrying on research on physiologically active compounds from marine organisms that have yielded several new antibiotics. These have been isolated, identified, and, in some cases, synthesized. His group has studied the role of antibiotic formation as a chemical defense mechanism for marine bacteria. While antibiotics can act as a defense mechanism in the open ocean, they are autotoxic under laboratory culture conditions. An investigation of the halogenated natural products in the skin of *Aplysia californica* has revealed that some of the less polar chemicals from the digestive gland, an organ in which large quantities of halogenated metabolites are stored, are transferred to the skin. These chemicals could be responsible for the sea hare's freedom from predation. The routes by which halogens are introduced into algal metabolites is being studied for both monoterpenes and sesquiterpenes.

Dr. Charles D. Keeling's CO₂ group has continued with their investigation of the geochemistry of carbon dioxide, with emphasis on air-sea interaction processes. An investigation of periodicities in atmospheric CO₂ concentration by Dr. Robert B. Bacastow has revealed an unexpected correlation of barometric pressure anomalies near the equator with anomalies in the CO₂ trend at the South Pole. In 15 years of record, CO₂ has shown unusually high rates of increase four times. Each occurrence has come approximately one year after a period of abnormally low barometric pressure difference between Point Darwin, Australia, and Easter Island. This pressure difference is a well-known indicator of the so-called Southern Oscillation, a fluctuation in the strength of the zonal winds with a period of about two-and-one-half years. Low-pressure difference corresponds to weak zonal circulation. It is speculated that either less CO₂ is removed from the atmosphere by the southern oceans during periods of weaker winds, or that meridional transport from the industrial sources in the Northern Hemisphere is increased.

Dr. Keeling and his associates, in cooperation with the New Zealand Institute of Nuclear Sciences, have been measuring atmospheric CO₂ near 40°S on the New Zealand coast and are presently establishing a sampling station at Christmas Island on the equator in order to improve Southern Hemisphere coverage with the view of better locating oceanic sources and sinks of CO₂. In further work, the CO₂ group has nearly completed a four-year recalibration of atmospheric standard gases used by laboratories throughout the world, and has continued to monitor atmospheric CO₂ in Hawaii, on a weather ship at 50°N, and at Scripps Pier. This latter program, a continuous operation since October, 1972, has produced a record of the influences of regional combustion on local air masses. The record indicates that when the air at Scripps is coming in from the sea, it is influenced over 90 percent of the time by man-made combustion, mostly from the Los Angeles area. Higher CO₂ levels are closely related to increasingly noticeable "smog" episodes. Com-



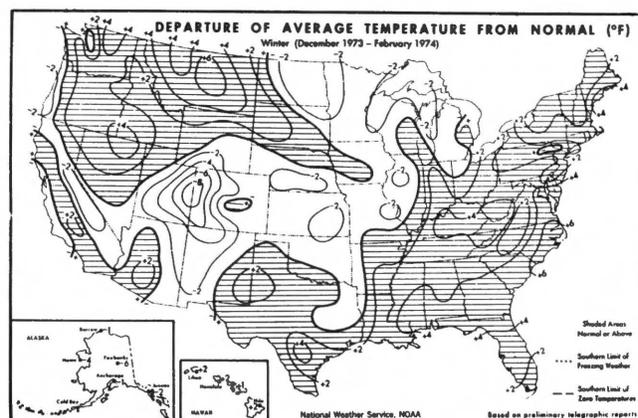
R/P FLIP, left, and R/V Thomas Washington participated in NORPAX's first field experiment in the North Pacific during January-February, 1974.

U.S. Navy



Gerard J. McNally, left, a development engineer for the North Pacific Experiment (NORPAX) program, and Jack Lucas, right, electronics technician, maneuver a remotely tracked, small, drifting buoy from ship to shore at Nimitz Marine Facility after completion of preliminary NORPAX tests. Similar buoys were deployed in February, 1974, and tracked until June, 1974, for observation of currents in remote areas of North Pacific Ocean. Buoy was developed by Dr. William Richardson at Nova University of Advanced Technology, Ft. Lauderdale, Florida.

Jackie Janke



Weather forecast—made November 18, 1973—and observed temperature anomalies for the winter of 1973-74 are seen in this chart. Essentially, the pattern expected is for temperatures to average above seasonal normals over the eastern third of the nation, and also in the west Gulf states. Western half of country will be colder than normal. Elsewhere, about normal temperatures are anticipated, with large weekly variations between cold and warm spells.

National Oceanic and Atmospheric Administration

parison with similar data obtained from 1959 to 1961 indicates a doubling of air pollution levels, probably caused by urban growth.

Dr. Tsaihwa J. Chow has been studying the distribution of lead in marine environments, in particular, the occurrence of lead in tuna. Four types of samples have been analyzed: (1) uncontaminated tuna muscle, which contains small lead concentrations of 0.0003 ppm; (2) tuna epidermis, in which lead is concentrated to 2 ppm level; (3) tuna dermis and scales, which contain much less lead than epidermis; and (4) commercial canned tuna muscle, which is contaminated with lead by a factor of 1,000 above the natural level. Tuna muscle probably contains such small concentrations of metabolized lead because of biochemical exclusion mechanisms in the gut membrane. Most of the lead concentration occurs in the tuna epidermis, located in epidermal slime. The mucin secreted by the mucous cells of the epidermis contains a glycoprotein which reacts with water to form mucous slime. It is likely that strong heavy-metal complexing sites in these proteins withdraw lead from seawater and incorporate it into the slime.

The uptake of lead by *Scorpaena guttata* (Scorpion fish) in the lead-dosed seawater has been determined. After the initial increase, the lead content of gills, fins, skin, and scales of *S. guttata* remained relatively unchanged throughout the experimental period of 90 days. The largest percentage increase of lead was found in the liver, kidney, spleen, and digestive tract. The bones showed only a slight increase in lead content, and no appreciable increase in lead was detected in the muscle.

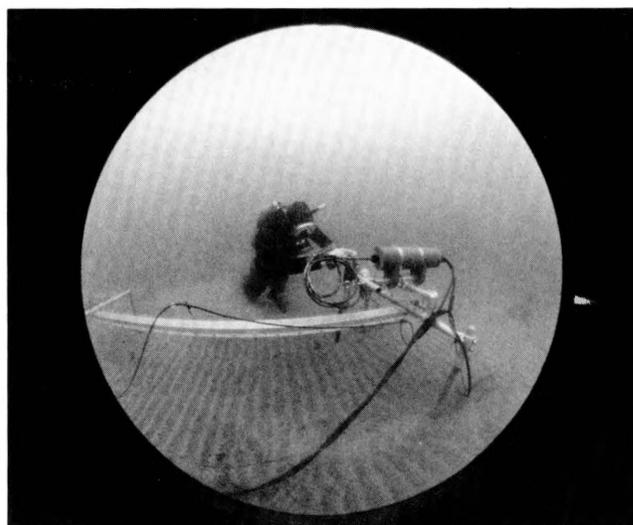
Coastal marine sediments provide chronological records of chemical discharge into the nearshore oceans. In cooperation with Dr. Edward D. Goldberg's laboratory, Dr. Chow determined that the present anthropogenic lead fluxes into sediments from the Santa Monica, San Pedro, and Santa Barbara basins of southern California are, respectively, 0.9, 1.7, and 2.1 micrograms of lead per year per cm square of sea bottom; the natural rates for these three basins were, respectively, 0.24, 0.26 and 1.0 micrograms of lead per year per cm square of sea bottom. This increase of lead flux can be attributed to the fallout of lead aerosols from gasoline combustion.

Drs. Theodore R. Folsom and Vernon F. Hodge have continued their studies of the behavior of extremely small traces of artificial and natural radioactivities in the marine environment. Special attention now is being given to the fate of plutonium in the ocean and to how much of this hazardous artificial nuclear fuel material has been accumulated by marine organisms. For several years large oceanic fish have been routinely inspected. It has been found that little plutonium is accumulated in edible tissues of large marine animals. On the other hand, one natural alpha emitter, polonium-210, has been found to accumulate to levels thousands of times higher than those levels observed in man, especially in the pyloric caecal mass, which is almost never eaten by humans. These extreme natural radioactive burdens were previously not suspected, and their origins and consequences are not yet understood.

In Dr. Joris M. T. M. Gieskes' laboratory, further studies were conducted on the composition of interstitial waters of marine sediments. Special attention was given to samples obtained from the Deep Sea Drilling Project. Dr. Gieskes took part in Leg 35 of this project to the Bellingshausen Sea. Additional studies on the chemistry and mineralogy of the solid phases of these sediments, as well as oxygen isotope studies (Dr. J. Lawrence, Lamont-Doherty Geological Observatory), have made it possible to identify the reactions that are often the cause of observed chemical gradients in the pore fluids (mainly alteration of volcanic ash, glass, and/or underlying basalt). Also, extensive analyses were made on interstitial water obtained from box cores in the Gulf of California. This work is still in progress. Other studies have included the solution behavior of silica in seawater and analyzing in great detail the geochemistry of Deep Sea Drilling Hole 253 on the Ninetyeast Ridge.

The Shore Processes Study Group, under Drs. Douglas L. Inman and Clinton D. Winant, has been engaged in studying the physics of the nearshore environment. Research objectives of this group include: (1) field and laboratory measurements of winds, 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) formulations of criteria for coastal zone planning.

The basic research objective of making meaningful field measurements in the nearshore environment is attained with the use of versatile



Dr. John R. Dingler measures sand ripples generated by waves on ocean bottom near Scripps Pier. The long beam supported by legs is used to support a high-resolution sonic device utilized to profile accurately the sand bed in the presence of waves. Apparent curvature of beam originated from distortion caused by "fish-eye" camera lens.

Shore Processes Study Group

instrumentation that was developed by Robert L. Lowe of the group. The Shelf and Shore (SAS) simultaneous data system consists of several shelf stations deployed offshore for measuring data and a shore station for receiving and recording data. Each shelf station is a buoyant spar that is coupled to an anchor on the bottom by a universal joint. A variety of sensors can be attached to each shelf station for making measurements of waves, currents, and temperature that are then transmitted back to the shore station. The shore station can receive data from several shelf stations simultaneously and record them for later processing.

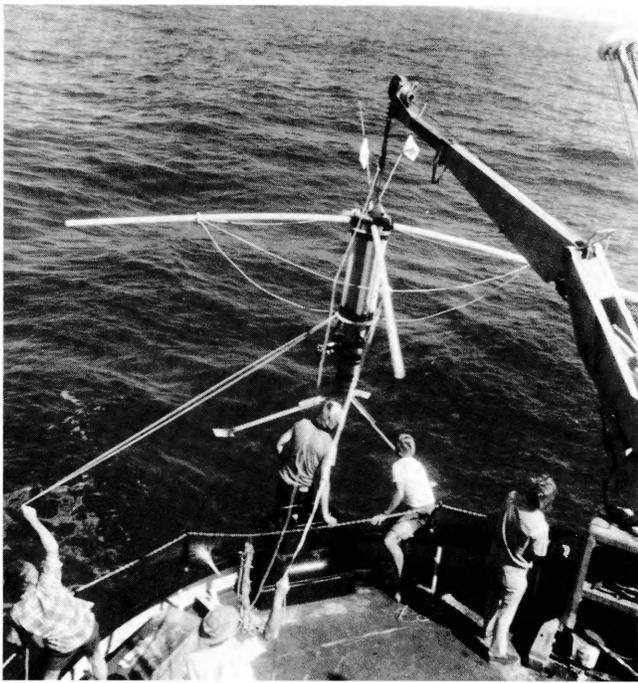
Shelf stations have been installed off Torrey Pines Beach (three km north of Scripps) and in the head of Scripps Canyon (see illustration). The Torrey Pines Beach station is used to measure the local wave climate from a line array of pressure sensors on the bottom. A two-year study of wave climate, using this array, has been completed. The second shelf station in Scripps Canyon is designed to measure currents in this submarine canyon. This station is part of a continuing study of the occurrence of strong currents in submarine canyons.

Dr. Winant and graduate student Scott Jenkins are investigating the presence and nature of breaking internal waves and bores in the nearshore environment, using an array of thermistor chains and pressure sensors in the vicinity of Scripps Pier. Breaking internal waves cause large temperature changes to occur in shallow water, sometimes quite rapidly. Bottom temperature changes on the order of 5°C have been measured at the end of Scripps Pier, occurring in a few seconds. These temperature changes are accompanied by currents of the order of 10 cm/sec which last for a period of several hours. Such currents are thought to have a significant role in transporting sediment in shallow water.

Laboratory experimentation by Dr. Robert T. Guza shows that a very strong subharmonic edge wave resonance occurs when single-frequency incident waves are surging and strongly reflected by the beach. Large subharmonic edge waves on plane laboratory beaches rearrange sand tracers into accumulations that resemble natural beach cusps. Small edge waves form longshore periodic morphologies by causing perturbations on the beach berm; in this case, retreating incident wave swash is channelized into breaches in the berm caused by the edge waves.

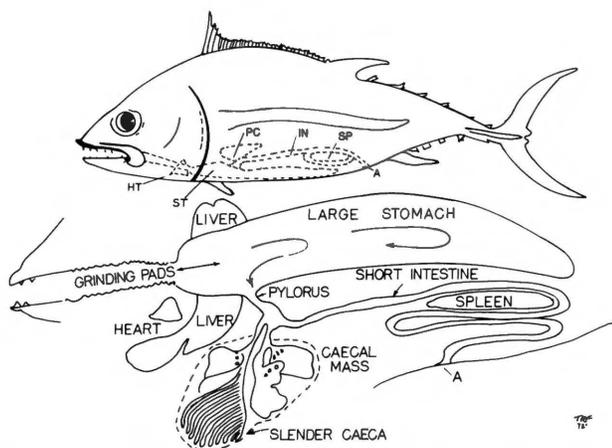
Dr. John R. Dingler, using a newly developed sonic bed profiler that could very accurately measure the ripple height, investigated the geometry of sand ripples formed on the bottom (see illustration). It was found that the ripple geometry is controlled by the size of the sand and by the nature of the fluid motions caused by the waves.

Charles E. Nordstrom and Dr. Inman completed a two-year study of seasonal sand level changes at Torrey Pines Beach in which monthly



Two-component, horizontal, electric field, ocean-floor recorder just prior to its launching. Small voltage differences—a few microvolts—are sensed between tips of the four arms. They are recorded within the vertical pressure case on magnetic tape. Instrument has a 6-m span and is 2 m high. Its weight on deck is 75 kg, and it has an autonomy of 150 days.

Michael Kirk



Sketch locates, in the North Pacific Albacore, the little-studied viscera organ called the pyloric caecal mass that has been found to carry perhaps the highest burden ever recorded for a natural radioactivity in any marine animal. Natural polonium-210 in this organ is often concentrated more than 2-million-fold above the concentrations typical of environmental seawater. Satisfactory explanations are being sought.

Drs. Theodore R. Folsom and Vernon Hodge

beach profiles were measured on three range lines along a 2.6 km segment of beach. Drs. Winant and Inman and Nordstrom are applying empirical eigenfunction analysis to these data in order to objectively represent the variation in beach profile configuration. From this statistical analysis, it was found that three eigenfunctions account for most of the variance in the profile data. The function that accounted for most of the variance is a mean beach function that defines a mean profile line between the extreme profiles measured. A second function, called the bar-berm function, has a maximum value at the locations of the beach berm in summer and a minimum value at the location of the offshore

bar in winter, indicating its relations to the seasonal onshore-offshore movement of sand. The third eigenfunction has its maximum value at the location of the low-tide terrace, and it is called the terrace function.

Dr. Inman and Rolland Harris, dredging consultant, have been investigating an improved technology for artificially moving sand. These studies involve the crater-sink, sand-transfer system supplemented with a fluidizer. Work on this study over the past two years has progressed from laboratory studies in the granular-fluids basin at the Hydraulics Laboratory to a field study of the entire system.

The sand bypassing system tested at Oceanside, California, intercepted sand carried by littoral drift and pumped it to an inshore deposition area. The sand was initially collected in an 18-m-long trench generated by a fluidizing pipe. The sand was transported along the length of the trench into an onshore crater that was maintained by a jet pump. The sand was discharged 75 m inland from the crater. During the prototype test period, beach profiles, crater-trench profiles, and aerial photographs were taken. The results of the field tests, although inconclusive, demonstrated that the prototype system did intercept littoral drift in spite of the deliberately adverse conditions established by the investigators.

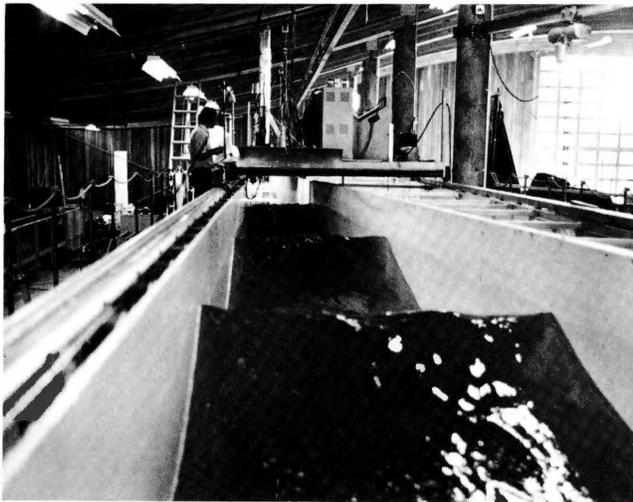
Dr. Paul K. Dayton and his group continued a broad range of near-shore ecology studies that included research in local kelp, sand bottom, and intertidal communities, as well as several projects at McMurdo Sound, Antarctica. The kelp-bed research involves studies of the individual growth rates, recruitment, and mortality patterns of several kelp species, the foraging patterns and effect of their herbivores, and the community implications of several carnivores. Other projects include studies of the population dynamics of species that encrust the kelp fronds, and of underledge populations of sponges in kelp beds and in the Antarctic. Sand-bottom research includes studies of encrusting communities on artificial rocks, of foraging strategies of sand-bottom starfish, and of research evaluating the effects of foraging of several guilds of fishes on the sand infaunal community. Aspects of intertidal ecology are being investigated, along with studies of the ecology of *Sargassum muticum*, an invading seaweed; problems related to the ecology of animals that depend on large seaweeds as habitats; and the development of a model of several intertidal interactions. Finally, a sponge community project in McMurdo Sound is continuing in conjunction with a new study of the soft-bottom community.

Dr. James T. Enright has, over the past year, been involved in experimental work designed to elucidate the physiological processes underlying endogenous tidal and lunar rhythmicity of a small intertidal crustacean. Two-hour treatments with mechanical stimuli that mimic wave action during high tide serve to induce significant phase shifts of the tidal rhythm; the direction and magnitude of the resultant shift depend predictably upon the phase of the rhythm at which treatment is administered. A surprising interaction between the effects of heavy water (D₂O) and environmental temperature on the free-running rhythm has also been encountered, such that at 10°C, a given dosage of D₂O lengthens periods to a much greater extent than at 20°C.

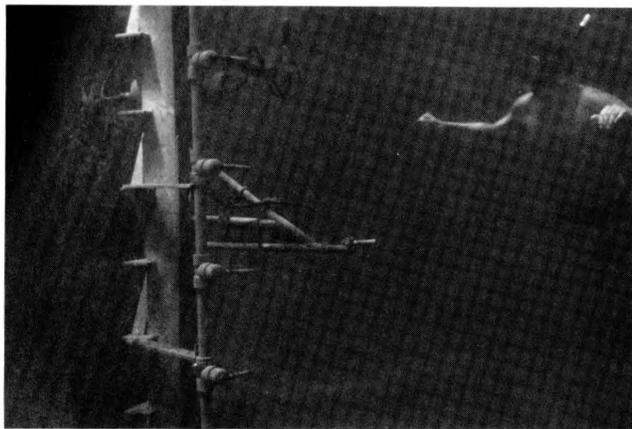
Continuing studies of sun orientation by talitrid amphipods have revealed an effect of "light pollution" on their behavior: the searchlights on Scripps Pier have apparently led the amphipods on this beach to abandon their usual time-compensated sun orientation, and to respond to the sun as though it were one of the searchlights, thus leading to very different directional choices by animals from north of and from south of the pier.

Dr. Jeffrey L. Bada continued his research and experimentation with racemization of amino acids, in particular the racemization reaction involving aspartic acid, which has one of the fastest racemization rates of any of the stable amino acids. Results from previous experiments have provided evidence that the aspartic acid racemization reaction is an important chronological tool for dating fossil bones that are either too old or too small for radiocarbon dating. This new and powerful tool is now being used to study conditions that prevailed in continental regions during glacial epochs.

Objective design and analysis of oceanographic experiments have been under examination by Dr. Russ E. Davis. Methods of designing arrays to obtain synoptic maps of oceanographic variables were developed for MODE (Mid-Ocean Dynamics Experiment). These methods are being applied to designing sampling schemes to study the upper ocean heat budget as part of NORPAX (North Pacific Experiment). A related study concerns the measurement of directional wave spectra. The design methods are also being applied to the design of POLY-



Steep waves are shown here being converged to the breaking point in the Hydraulics Laboratory wind-wave channel.



Experimental apparatus for taking vertical temperature scans is installed on sea floor at end of Scripps Pier.

Shore Processes Study Group

MODE, the successor to MODE, which is attempting to determine the energy sources for mesoscale motions and their influence on the general oceanic circulation.

Dr. Robert A. Knox continued a project to obtain regularly repeated temperature and velocity profiles near the Indian Ocean equator. More than a year and a half of weekly soundings, with a few gaps, have now been obtained. The response time relative to the local winds of surface currents and of such deeper flows as the undercurrent, is quite short, about one month. Since one can find periods of several weeks, especially at the changes of monsoon in fall and spring, during which the winds show pronounced longitudinal variation along the equator, the question arises as to whether the equatorial currents somehow develop similar longitudinal structure. In conjunction with other investigators, Dr. Knox hopes this winter to begin exploratory measurements of this aspect of the variability.

Based on recent results from MODE, in the Sargasso Sea, demonstrating the effectiveness of electric field recordings on the sea floor in using small-sized instruments (see illustration), Drs. Jean H. Filloux and Charles S. Cox have initiated various projects to exploit the opportunity for electromagnetic investigations of the electrical conductivity structure of the oceanic crust and upper mantle. They also plan to employ these instruments to study the larger-scale, oceanic, barotropic motions. In order to satisfy the necessity of broad, observational coverage, sizable arrays of electric and magnetic field recorders are envisioned. Thus, efforts have been made to optimize size, performance, methods of deployment, and costs of the necessary instrumentation.

Drs. Theodore D. Foster and Eddy C. Carmack continued with the evaluation of the physical oceanographic data obtained during the 1973 International Weddell Sea Oceanographic Expedition. Detailed analyses have confirmed preliminary conjectures regarding the formation of Antarctic Bottom Water by a three-stage process. In addition, it seems likely that Antarctic Bottom Water can form the year around in the western and possibly southern parts of the Weddell Sea. Preparations are being made for another expedition to the Weddell Sea during which it is hoped to survey the hitherto unexplored, western part, and to emplace current meters to monitor the flow of bottom waters over an entire year. Dr. Carmack completed a volumetric T-S census to show the statistical distribution of the primary water masses in the Weddell Sea and their mean oxygen and nutrient properties.

Dr. Foster's group has been investigating the development of larger-scale convection cells from smaller-scale cells in laboratory experiments by using a Hele-Shaw cell and by numerical experiments using a computer; he has also developed a numerical model for heat exchange in the Arctic Ocean.

The research activities of Dr. Carl H. Gibson's group were concerned mainly with the roles of turbulence in the oceans and atmosphere. Considerable effort the past year was toward the further development of very-low-noise, high-frequency-response measuring systems for temperature and velocity in the ocean and atmosphere. Recent atmospheric measurements have been made by Dr. Carl A. Friehe, from R/P FLIP for NORPAX, and by Drs. Frank H. Champagne and John C. La Rue, in Japan, for AMTEX (Air-Mass Transformation Experiment). While he was on sabbatical last year, Dr. Gibson made atmospheric measurements in Denmark and in a large, air-sea interaction, wind-wave tunnel at Marseilles, France.

Small-scale measurements of temperature and velocity in the ocean were made last year with a horizontally towed instrument package. These measurements were from R/V *Thomas Washington* in the Kuroshio Current and during an intercomparison experiment with Soviet scientists aboard R/V *Dimitri Mendeleev* west of Tasmania. Of particular interest for these data is a study of the relationship of the presence or absence of turbulence to the fine structure of the vertical density distribution in the upper thermocline.

Dr. Myrl C. Hendershott continued work on global prediction of tides, and studied the influence of gentle but persistent perturbations of large-scale fluid systems on the statistical properties of large-scale fluid flows, such as those that occur in the ocean and in the atmosphere. In the ocean, such persistent perturbation is provided by bottom relief; in the atmosphere, it is provided by the ocean-continent contrast in air-sea heat flux. In the ocean, this work aims at elucidating the role of bottom relief in constraining the effect of oceanic mesoscale eddies on large-scale ocean flows, while in the atmosphere it seeks to describe some of the effects of the heat flux associated with sea-surface temperature anomalies in the atmosphere.

Drs. Cox and Michael C. Gregg have examined the distribution of very small-scale temperature and salt structures in the ocean. The intensity of microfluctuations is a measure of the local intensity of mixing. Analysis of data obtained in the thermocline in the center of the subtropical gyre in the North Pacific shows that the intensity of mixing is very weak. If this result is generally true, then the structure of the thermocline must be established by lateral motions rather than by eddy diffusion in the vertical. These results were obtained in early fall, before winter winds stirred up the water. Later studies, for which analyses are still in progress, have taken data in typical spring and winter conditions.

Dr. William G. Van Dorn completed a two-year laboratory investigation of the dynamics of periodic, deep-water, wave trains laterally converged to the breaking point in a tapered channel section (see illustration). The object of the study was to examine, in some detail, the profiles and flow fields within steep waves as they increased in height toward breaking in a search for invariant parameters that control breaking inception and intensity. This required the development of special, high-speed-measurement techniques, so that contour plots of particle velocities could be produced as functions of time and distance.

The results, most of which are new and not predicted by current wave theories, can be summarized as follows:

- (1) Irrespective of frequency, the amplitudes, wavelengths, and phase velocities of individual waves increased smoothly toward the breaking point, and growing waves remained fairly symmetrical until about one wavelength before breaking.
- (2) At the breaking point, characterized by cessation of growth and

the appearance of turbulent instability on the forward face, peak particle velocity under the crest equaled phase velocity, and maximum steepness approached the theoretical limiting steepness for "stationary" waves: $H/L=0.14$. However, all crests were markedly asymmetrical (forward face concave), and the degree of asymmetry qualitatively increased with breaking intensity.

(3) Increased profile asymmetry near breaking was reflected internally by corresponding asymmetry in isolines of constant particle velocity, which tended to tilt increasingly forward as breaking was approached. In violent breaking, the near-crest isolines actually wrapped around to form a plunging jet, within which velocities were measured that exceeded the wave-phase velocity by as much as 40 percent.

(4) Breaking intensity appears to be governed by the rate of channel convergence per wavelength; thus, the energy lost by breaking is related to the rate of increase of energy density during the growth phase. However, the rate of increase of potential energy density consistently fell below that expected from the channel convergence rate, indicating a possible transfer to kinetic energy. This view is supported by an observed increase in horizontal momentum flux beneath the crests that increased with breaking intensity.

Physiological Research Laboratory

Drs. Per F. Scholander and Harold T. Hammel have collaborated in preparation of a monograph, *Tensile Water in Osmotic Processes*. The book reviews the history of the concept of tensile water and its relation to osmotic processes. Movement of water in vascular systems of plants and in animal tissues is interpreted on the basis of a consistent system of physical relationships described in thermodynamic terms. The extensive series of model experiments, which have been devised by Drs. Scholander and Hammel and their colleagues during the past 15 years, has been brought to focus in the system described as "tensile water."

Regulation of body temperature in vertebrates is accomplished by temperature-dependent neurons in the basal forebrain and hypothalamic nuclei. Dr. Hammel and his associates continue to investigate how these neurons are affected by sensory inputs from temperature receptors in the skin and from proprioceptors in the muscles and joints, how they are affected by sleep and hibernation, and how they activate behavioral and autonomic thermoregulatory responses. Thermodes were implanted around neural tissue in the rostral brainstem of harbor seals, Adélie penguins, dogs, and box turtles. Thermoregulatory responses were elicited by altering the temperature of the neural tissue above and below the body temperature of these species. Quantitative measurements of these responses, which include shivering, salivation, panting, and increased blood flow to the skin surface enhance man's understanding of the regulation of body temperature and the evolution of this function in the vertebrate body.

Dr. Edvard A. Hemmingsen carried out studies on cavitation caused by gas-supersaturation in water and other liquids. It was of particular interest to establish the extent that gas-supersaturation is required for the spontaneous formation of bubbles at various types of water-solid interfaces, in the absence of pre-existing gas nuclei. The main objective of these investigations is to obtain information on the physical factors that determine the onset of the cavitation. This information is of importance for understanding the mechanism for the appearance of bubbles in organisms during certain conditions of decompression.

Much of marine life proceeds at the great pressures of the deep sea. Dr. A. Aristides Yayanos is studying the molecular bases of adaptation to such hyperbaric conditions. (1) Examination of the thermodynamic relationships underlying deep-sea phenomena is continuing with the determination of the pressure dependence of partial molal volumes. A large pressure effect on the partial molal volume of magnesium sulfate, an important component of seawater and biological fluids, has been observed. Theoretical bases of biological consequences of this large pressure effect are being explored. (2) An investigation into the pressure sensitivity of protein-protein interactions has been initiated with the determination that the trypsin-trypsin inhibitor (ovomucoid) reaction is relatively insensitive to pressure changes as great as 2,000 atm. (3) The process of bacterial cell division and its relationship to DNA synthesis has been studied at high pressures. A high-pressure device has been constructed that can retrieve organisms from the greatest depths of the sea with maintenance of their native pressure and temperatures. Cellu-



Dr. Gerald L. Kooyman, of the Physiological Research Laboratory, is photographed at Port Lockroy, Antarctic Peninsula, during studies of behavior of Gentoo penguin, one of which is shown with him.

Physiological Research Laboratory

lar processes in living, deep-sea bacteria recovered from a depth of 7,000 m in the Aleutian Trench are under investigation.

Dr. Gerald L. Kooyman continues his studies of respiratory function in aquatic vertebrates. These studies deal with the structural nature of the lung and how it relates to gas exchange and ventilation. The underlying theme is the behavioral, physiological, and anatomical adaptations that have occurred in vertebrates that swim at high speeds and dive to great depths.

A survey is in progress of the microstructure and airway branching of the lungs of marine mammals and reptiles. In collaboration with Dr. David Denison, now at the Royal Air Force's Aeromedical Research Laboratory, Dr. Kooyman completed a study of pinniped and sea otter lungs. From this work it was learned that the lung microstructure of seals seems the least different from terrestrial mammals, and that of sea lions the most modified. The lungs of the latter are very similar in airway structure to those of whales. In an attempt to better understand what these structural variations mean, the mechanical properties of the lungs of bearded seals and walrus were studied during an *Alpha Helix* expedition to the Chukchi Sea. The field work on this project was carried out by Dr. Dan Kerem, of Duke University.

It is believed that some of the anatomical modifications may be caused by the unusual ventilatory needs of the animals: *i.e.*, the explosive blows of the whales. In order to understand the physical nature of the blow, such as its duration, the gas flow rate, and tidal volume, special pneumotachygraphs are being designed and constructed. This effort has benefited greatly from the assistance of Dr. David Leith, of Harvard University. Last year, during Dr. Kenneth S. Norris' (UC-Santa Cruz) gray whale expedition to Baja California, it was possible to make detailed observations of ventilatory behavior of cow and calf under a variety of conditions, and to use one of the pneumotachygraphs. The data from this study are now being analyzed.

Because it is believed that many clues about function can be obtained by studying the stages of structural development of the lung, Dr. Kooyman began a study of lungs from various-sized fetuses of spotted and spinner dolphins. Robert Garvie, a graduate student in the UCSD School of Medicine, made two cruises aboard tuna seiners to collect

and preserve fresh material, and to characterize the mechanical properties of the lungs of adult animals.

Sea turtles and sea snakes are afflicted with many respiratory problems similar to those of marine mammals. The lungs of reptiles are much simpler, however, and consequently, they make useful models for comparison. This past summer a major study of the effects of compression on gas exchange in yellow-bellied sea snakes was completed in Panama in collaboration with Dr. Jeffrey Graham, of the Smithsonian Tropical Research Institute.

The blood of the Antarctic cod *Dissostichus mawsoni*, like other Antarctic fishes, is fortified with novel glycoproteins that serve as "antifreezes" and permit them to avoid freezing at -1.9°C , the temperature of the water in McMurdo Sound, Antarctica. A field party under the direction of Dr. Arthur L. DeVries returned to Antarctica in 1973 to study this unique adaptation.

The distribution of the glycoproteins within the fish was determined by using radioactive, labeled, glycoprotein antifreezes of several molecular sizes that were prepared in the laboratory. They were found in the coelomic fluid, pericardial fluid, and intracellular fluid, but not in the bile nor in the urine. The absence of the smallest glycoproteins (molecular weight of 2,600 daltons) in the urine is extremely unusual, because, in most vertebrates, the process of urine formation involves filtration of water and small solutes from the blood into the urine by the many glomeruli in the kidneys.

When inulin, a polysaccharide of a molecular weight of 5,500 daltons, is introduced into the blood of most animals, it is quickly filtered by the glomeruli into the urine. In the Antarctic fishes, the inulin was always retained in the blood, thus indicating kidney glomeruli are absent. By microscopic observations of serial sections of kidney preparations, graduate student Gary H. Dobbs, III, confirmed the discovery and that they are indeed aglomerular. The Antarctic fishes maintain high levels of glycoproteins in their blood (four percent weight/volume) because no filtration occurs in their aglomerular kidneys. Because glomerular filtration does not occur, no energy expenditure is required for reabsorbing the glycoproteins or other blood proteins. Thus, the metabolic cost of osmoregulation in Antarctic teleosts may be considerably different from that in other marine teleosts.

All the waters south of the Antarctic convergence are near the freezing point during the winter. For fish to exploit these food-rich waters, some protective mechanism against freezing must have evolved. Agglomerulism may have played an important role, because it permitted utilization of a wide range of sizes of glycoprotein antifreeze molecules without requiring energy expenditures for their tubular reabsorption.

Freezing resistance in several fishes inhabiting the waters of the northeastern part of North America was investigated. Graduate student John G. Duman demonstrated that the serums of these fishes have different melting and freezing points; this indicates the presence of antifreeze compounds. Such a compound, isolated from the winter flounder, *Pseudopleuronectes americanus*, is a relatively large molecule. In contrast to the glycoprotein structure of serum antifreezes found in the Antarctic fishes, this one is a protein. This discovery is of particular interest because it reveals the fact that fishes from these different geographical areas have evolved rather different freezing protectant compounds. Dr. DeVries and his associate, Dr. Yuan Lin, have found, further, that these antifreeze compounds cause freezing point depression in a remarkable way that preserves the ionic and osmotic balance essential for life of the fish.

The nototheniid fishes of McMurdo Sound exhibit a swimming pattern differing from that found in most other fishes. At slow, sustained speeds, these fishes propel themselves by their large, fan-shaped, pectoral fins, and use their tail only for steering. To escape predators, the fishes use their tails for swimming in brief bursts. The musculature that covers the pectoral girdle and articulates the pectoral fins is red, while that associated with tail movement is white. In other fishes, both red and white muscles drive the tail and their functions cannot be easily separated.

The distinct localization and specific function of the red and white muscle-masses in these Antarctic fish are obvious. They are ideal subjects for relating function to metabolic requirements. Measurements of oxygen consumption of the red and white muscles from *D. mawsoni* showed that the consumption of the red muscle is seven times greater than that of the white muscle at their environmental temperature of -1.9°C . Electron micrographs of the red muscle reveal that the inter-

fibrillar region is filled with large numbers of lipid droplets surrounded by mitochondria and that very few glycogen granules are present. These findings by Gary H. Dobbs, III, who collected the specimens on a previous expedition, indicate that lipid, rather than glycogen, is the energy source for these muscles. The large number of mitochondria and the complexity of their cristae indicate a high metabolic rate that is consistent with their rapid oxygen consumption.

Visibility Laboratory

Visible light is an important source of information in many kinds of oceanic and atmospheric scientific investigations. The 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. The Laboratory also studies the fundamentals of the extraction and interpretation of the received image information.

The following examples illustrate the diversity of current research activities:

Optical Oceanography

Research related to the propagation of light in seawater remains the largest single activity of the Visibility Laboratory. Using an indoor water tank research facility, Drs. Seibert Q. Duntley and Wayne H. Wilson expanded upon their previously reported exploration of the manner in which water degrades the quality of in-water photography. A laser was used to form a submerged point source that was imaged through water. The structure of the image was documented by photoelectric measurements. This year's effort was directed primarily toward formulating the relationship between image quality and the scattering and absorption properties of the water. The resulting mathematical formulas allow computer synthesis of in-water imagery.

Improved measurement capability continues to be an important need for exploration of the optical properties of ocean water. Roswell W. Austin, Theodore J. Petzold, Richard L. Ensminger, and John D. Bailey continued their efforts to develop instrumentation to satisfy these needs. One new instrument will permit the measurement of scat-



Sue Barker



Simultaneous airborne and ground-based measurements of optical atmospheric properties were obtained near Mt. Rainier, Washington, during one of several joint programs conducted by the Visibility Laboratory and the U.S. Air Force Cambridge Research Laboratories. Acquisition of such data has continued for several years on a world-wide basis to provide investigators with valuable information about the dependence of these properties on altitude, geographical location, season, and type of air mass.

U.S. Air Force

tering and transmittance as a function of depth down to 500 m. Any one of a series of ten spectral filters can be remotely selected. The instrument also measures temperature to allow a study of the correlation between the thermal structure of the water column and the location of turbidity layers. All instrument functions are controlled by digital command from the surface, and the digital data from the underwater sensor is transmitted to the surface for processing and recording.

Under the direction of Austin, the Laboratory continued its studies of the oceanographic information that can be extracted from remotely sensed optical data. Measurements of the spectral irradiance of light falling upon the sea surface were made for a variety of solar elevations and atmospheric conditions. The measurements were made in such a way as to allow separation of the irradiance components caused by sun and sky. Measurements were also made of the sky radiance in order to allow calculation of the spectral radiance returned by the specular reflection of the sea surface. Dr. Wilson continued his work in computer modeling for the remote sensing of the sea surface. This simulation capability allows the prediction of the apparent sea-surface radiance seen by a satellite sensor, based upon lighting data of the type just described, vertical distribution of phytoplankton in the water, detailed reflectance properties of the sea surface, the distribution of white water as a function of wind velocity, and the obscuring properties of the atmosphere. One goal of such modeling is the hope of developing valid means for remotely assessing the phytoplankton crop in the euphotic zone of the sea.

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 that is assigned to the Laboratory for this purpose.

The instrumentation of this aircraft has been accomplished over a period of many years. The aircraft and instruments form a very 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 obtain a detailed knowledge 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.

The major field expedition during the reporting period involved an extended period of flights in the Florida region. The remainder of the year has been devoted to data reduction, instrument redesign, and instrument calibration in preparation for a field trip to the northwestern United States.

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 equipments, 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.

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 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.

Computer simulation of in-air imagery in the presence of atmospheric turbulence has also been the subject of effort by McGlamery. The primary purpose of this study is the evaluation of techniques for improving image quality, either in terms of optical design or post-detection processing.

The image-processing facility has also been used in connection with studies involving visual aspects of safe aircraft operations. James L. Harris, Sr., and Gerald D. Edwards have been conducting studies of the visual stimuli required by a pilot for the purpose of judging the correctness of his approach to a runway for landing. Computer movies were generated showing the last minute of an approach to landing as it would appear from the aircraft cockpit. Some of the movie sequences showed landings in which the touchdowns would be long and some showed landings in which the touchdowns would be short. Professional pilots viewed these films, and responded throughout the film by operating toggle switches to indicate whether they believed they would be long or short. The data collected are used to quantify the accuracy with which such judgments can be made.

Institute of Geophysics and Planetary Physics

The Institute of Geophysics and Planetary Physics (IGPP) is a University-wide Institute with branches at Scripps Institution and the general campuses at Los Angeles, Riverside, and Davis. The Institute at La Jolla is intimately related to Scripps Institution, not only because of geographical proximity, but more importantly, because of common scientific interests. Drs. George E. Backus, J. Freeman Gilbert, Richard A. Haubrich, Walter H. Munk, and Robert L. Parker hold joint appointments in IGPP and Scripps. Dr. James N. Brune, Sir Edward C. Bullard, and Dr. Myrl C. Hendershott hold Scripps appointments; their offices are located at IGPP. Dr. Ralph H. Lovberg holds a joint appointment in IGPP and the Department of Physics of UC-San Diego. Drs. Hugh Bradner and John W. Miles hold joint appointments in IGPP and UCSD's Department of Applied Mechanics and Engineering Sciences. Drs. Jonathan Berger, William A. Prothero, Frank E. Snodgrass, and Wendell S. Brown and Bernard D. Zetler have senior research appointments in the Institute. Dr. Christopher Beaumont is a visiting Cecil H.



Sue Barker

and Ida Green Scholar in Earth Sciences.

During 1973-74, Dr. Brune was involved with seismic studies in Mexico, studies of the source mechanism of earthquakes, studies of seismic hazard in the San Diego area, modeling the strong motion pattern of earthquakes using a stressed, foam-rubber model, and oceanic seismic studies. With two graduate students from Mexico, Alfonso Reyes and Alejandro Nava, and in cooperation with Dr. Cinna Lomnitz of the National University of Mexico and Fred Mooser, of the Mexican Federal Power Commission, Dr. Brune carried out field studies and initiated a permanent seismic array in the Colorado Delta area of Mexico. In association with Drs. Prothero and Bradner and several graduate students, Dr. Brune has continued ocean seismic studies using both ocean-bottom seismographs and sonobuoys. Three deployments of a three-station array of this instrumentation on the crest of the East Pacific Rise and Rivera Fracture Zone by Dr. Prothero, Ian D. Reid, and Michael S. Reichle have resulted in the recording of hundreds of earthquakes. In order to understand the pattern of strong motion expected around major earthquakes, a foam-rubber model has been set up with dislocations that slip when stressed in the same manner as earthquakes. In this way, the maximum particle velocities and accelerations are related to other parameters of the dislocation; for example, the stress drop and rupture velocity.

Sir Edward Bullard has started work to revise the reassembly of the continents around the North Atlantic into the positions they occupied before the opening of the present Atlantic Ocean. The revision is desirable, since it is now possible to include data from the Arctic Ocean. He has also worked on the dynamo theory of the origin of the earth's magnetic field.

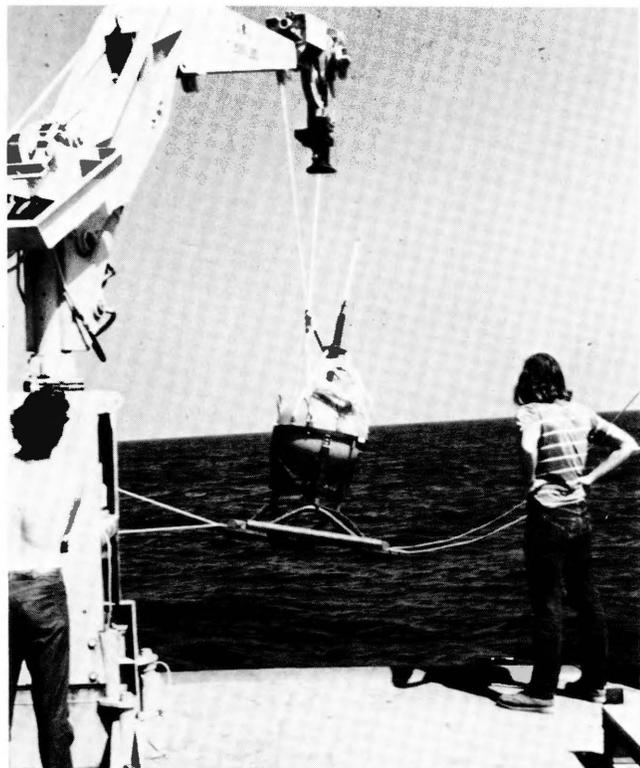
Dr. Gilbert's research continued in the observation of the earth's normal modes, the interpretation in terms of the mechanical structure of the earth, and the retrieval of the source mechanism of earthquakes. At present, 1,064 distinct normal mode frequencies have been observed. It appears from solutions of the inverse problem that the mechanical structure of the earth is very well constrained in detail at depths below 950 km, and that it is constrained in a gross average sense above that depth. In addition, the source mechanism of two deep earthquakes has been found, and it appears that both contain a significant compressive component; furthermore, the compressive component may precede the onset of the main shock by a minute or so.

Dr. Parker continued his work in the interpretation of potential-field data. The analysis of a large volume of near-bottom magnetic observations made by Dr. John D. Mudie and others of the Marine Physical Laboratory is almost complete, and has already given insight into the crustal creation process. Work has also continued on the rigorous the-

ory for bounding depth or density from a limited number of gravity measurements. Dr. Parker has written programs for handling arbitrary data sets in two dimensions that are currently being tested on real measurements.

Dr. Berger continued his studies of the seismotectonics of Southern California, using data obtained primarily at the Piñon Flat Geophysical Observatory. The Observatory contains a three-component, 800-m, laser strain meter in addition to a superconducting gravimeter, a La Coste modified gravimeter, a quartz-fibre gravimeter, an array of eight tiltmeters, three-component, long-period seismometers, and various environmental monitoring equipment. Work progresses on the deployment of a worldwide array of modified La Coste gravimeters to study the earth's normal modes and various aspects of the earth tides. Two instruments will be installed this year in Australia and Peru. In collaboration with Dr. Beaumont, Dr. Berger has conducted numerical modeling of the effects of ocean loading and lateral changes in the earth's elastic structure on the earth tides. A method of utilizing the earth tides as a sensitive detector of time varying changes in the nearby elastic parameters of the rocks has been developed and tested.

Drs. Munk, Snodgrass, and Brown and Zetler completed the analysis of their MODE (Mid-Ocean Dynamics Experiment) experiment southwest of Bermuda. The principal result was the discovery of bottom pressure fluctuations with horizontal scales of the order of 1,000 km, far beyond the MODE scales. Deep-sea tides were measured with sufficient precision to allow the determination of over-tides and of tidal gradients that could be compared to local measurements of tidal cur-



Graduate student Ian Reid, at left, prepares to launch one of three, free-falling, "pop-up" steel capsules off stern of R/V Ellen B. Scripps. Developed by Dr. William A. Prothero, at right, and Reid, their system for using seismic monitoring capsules to pinpoint even mini-earthquakes in the sea was successfully tested during March and April, 1974, when the capsules were deployed in a triangular array on and near crest of East Pacific Rise, off tip of Baja California. This operation marked first time that the three instruments functioned simultaneously for computing earthquake locations and depths by triangulation. The capsule is designed to fall freely to the ocean bottom, record as many as 1,000 events over a period up to a month, and then return to the surface to be recovered at a predetermined time, or upon acoustic (sound) command from a surface ship, with the use of a hydrophone.

Gary Newkirk

rents. James L. Cairns and Gordon O. Williams, using a Snodgrass mid-water capsule, obtained definitive measurements of internal waves, and learned that lenses of very strong microstructure were associated with local temperature inversions. Work is continuing on the transmission of sound through a "channeled ocean" with internal, wave-produced inhomogeneities.

Dr. Miles's work centered on the tsunami response of harbors and bays and on the foundations of Laplace's tidal equations. Variational approximations to the dominant resonant frequency of a harbor were developed (to be published in the *Journal of Fluid Mechanics [JFM]* in a joint paper with Y. K. Lee). A critical study of Laplace's tidal equations was completed (to be published in *JFM*).

Dr. Lovberg's long-laser, strain-meter experiment is nearing completion, and data obtained in recent months indicate that in its present embodiment, the long-laser system does not compete successfully with presently operating interferometers as an earth strain meter. The major difficulty is that mode-locking of the very long laser is sporadic by reason of a quantum-electronic instability in the argon discharge. Some final work is being done to determine the system's usefulness in applications requiring less sensitivity but inherent long-term stability.

Dr. Backus' areas of geophysical research during the year included (1) some problems in linear algebra related to calculating earth normal modes in which the earth's rotation cannot be treated as a small perturbation; (2) a proof of a uniqueness theorem for obtaining the geomagnetic field from satellite observations; (3) assorted solutions of non-linear and linear steady viscous flow problems related to the asthenosphere, along with some stability analyses; and (4) an attempt, not yet successful, to calculate some exotic aspects of the seismic signal from a double-couple source in a real earth.

Dr. Haubrich's search for the excitation sources of the Chandler wobble has continued. A new study of observed wobble vs. earthquakes gave no significant correlation. The atmospheric pressure excitation has been recalculated using "objective analysis"; the results show a not quite statistically significant correlation between atmosphere and Chandler wobble. Gravity measurements, covering more than a year, in the one- and two-cycles-per-day band have been analyzed. Earth tides have been resolved with signal to noise up to 80 db. The spectrum shows many of the peculiarities associated with ocean tide spectra, such as tidal cusps.

Institute of Marine Resources

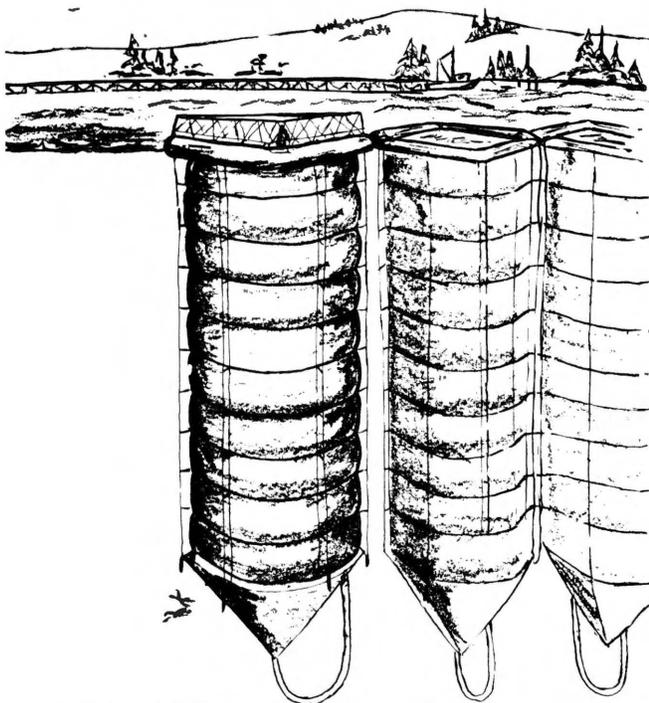
The Institute of Marine Resources (IMR), under the direction of John D. Isaacs, is concerned with research, education, and public service in the broad area of marine resources utilization. IMR provides a study basis for improving the supply of organic and mineral materials, and it fosters the gathering and dissemination of knowledge about such other resource components as transportation, disposal, pollution, and recreation at sea. It also provides for research into the social, legal, economic, and political aspects of man's related activities.

Administered from the Scripps campus, the Institute has facilities on several UC campuses. Its activities during the year were supported by a budget of \$236,350 and by contracts and grants of \$2,060,370. The latter includes the Sea Grant College Program budget of \$1,200,000 for all Sea Grant projects in California that are administered by IMR. An advisory council comprised of public members and an executive committee of faculty members assist the director on policy and on plans for research activities. Committee and council members are appointed by the President of the University of California.

Scientists affiliated with IMR carried out research in many disciplines during 1973-74. Sketched here are only the principal IMR activities undertaken at Scripps; that is, the work of the Food Chain Research Group (FCRG), of the Center for Marine Affairs (CMA), and of the local Sea Grant College program. A full account of this and other research is published in the periodic reports of IMR, FCRG, and Sea Grant.

Marine Food Chain Research Group

The Food Chain Research Group is an interdisciplinary group of scientists that investigates the organisms of the lower levels of the marine pelagic food web in relation to their physical and chemical environment. A major objective is to seek fundamental information for a better



Drs. Osmund Holm-Hansen, John R. Beers, and William H. Thomas, left to right, of the University's Institute of Marine Resources' Food Chain Research Group, examine a model of enclosures being used for studies at Saanich Inlet, off Vancouver Island, British Columbia, designed to help forecast long-term effects of pollutants on marine life should these continue to be added to the world oceans at the present rate. The international project, named Controlled Ecosystem Pollution Experiment (CEPEX), employs a team of researchers from seven oceanographic organizations, including Scripps. CEPEX has a projected cost of \$6 million over a six-year period as part of the National Science Foundation's (NSF) International Decade of Ocean Exploration program. Artist's sketch shows how the 10-m x 30-m, silo-like, underwater, plastic "test tubes" are utilized in CEPEX.

Sketch courtesy of University of British Columbia

understanding of energy transfers between trophic levels such that meaningful predictive models can be constructed. Field and laboratory studies are combined in order to identify, quantify, and gain insight into the physiological activities of organisms. In addition, members of FCRG are interested in developing new analytical techniques for plankton ecological studies. Major field programs include a study of the trophodynamics of phytoplankton and zooplankton in waters of the north central Pacific, those near sewage outfall areas, and those near nuclear power plants. Some FCRG members are involved in ecological studies in the south polar seas. Several scientists are taking part in the Controlled Ecosystem Pollution Experiment (CEPEX) in Saanich Inlet, Canada. From time to time various FCRG members take part in specific programs and cruises with personnel from Scripps and other institutions. Specific areas of studies include the (1) determination of natural radioactivity of dissolved and particulate organic matter in seawater; (2) metal analyses of seawater and organisms; (3) chemical composition of organisms, mainly for carbon, nitrogen, and phosphorus, total protein, carbohydrate, lipid, and specific molecules; (4) growth and activities of marine bacteria under conditions similar to the natural environment; (5) effect of the addition of chlorine and the resultant chlorinated organic compounds on phytoplankton growth; (6) experiments evaluating nitrogen, phosphorus, and silicon assimilation of phytoplankton; and (7) studies of microzooplankton and zooplankton distributions, in some cases culturing these organisms in the laboratory. These are but a few of the studies in which FCRG members are involved.

Center for Marine Affairs

Research activities of the Center for Marine Affairs, directed by Dr. Gerald L. Wick, began with a new study on environmental extremes. The study was preceded by a workshop in the summer of 1973 to stimulate open discussion between natural scientists and social scientists, and to develop possible approaches to this new study.

Four new Fellows were appointed to CMA as the nucleus of a research team to conduct studies on the control and utilization of environmental extremes. They included two political scientists, an economist, and an economic geographer.

This CMA study is an examination of long-range marine resource management issues related to desert coasts. Attention is focused on the extensive desert coastline of Baja California, as a case study, in order to illuminate key, marine-resource-management issues that have direct relevance to future resource utilization among desert coasts in general. In collaboration with scientists from Mexico, the CMA staff is working to evaluate the potential of various technologies along the Baja California coastline, and to examine how scientific knowledge and technology can be used to assist the Mexicans. Scientists at Scripps are also participating in this study. Other issues being investigated with regard to these desert coasts include the conflict inherent between short-term and long-term economic growth and development, the reconciliation of economic growth with conservation of the environment, and the relationship between national and international interests regarding resource utilization. Particular emphasis is on fisheries and aquaculture, tourism, and land-use planning.

The current CMA study is planned to last for at least two years, and to culminate in a comprehensive report suitable for publication as a book. Various government agencies of Mexico are supporting the collaborative program of research to be carried out in Baja California.

CMA researchers are also investigating political and economic aspects of manganese-nodule mining, management of the California anchovy fishery, and technoscientific assistance programs in the Third World.

In April, 1974, work was completed on the National Science Board's sixth annual report on "The Health of American Science," a project undertaken by Robert Bickner of UC-Irvine, who worked on the project at CMA with the assistance of Dr. Wick.

Drs. Wick, J. R. Stanfield, and Jack N. Barkenbus helped organize and participated in the American Association for the Advancement of Science's Western Division Symposium at Irvine.

Sea Grant College Program at Scripps

The University of California Sea Grant College Program is adminis-



Edward Renger, of Institute of Marine Resources' Food Chain Research Group, fills a spectrophotometer cell for measurement of nutrient concentrations in central Pacific seawater taken during *Tasaday I*.

Dr. Elizabeth Venrick



The University of California was designated the nation's seventh Sea Grant College "for sustained excellence in research, education, and public service dedicated to wise use of America's marine resources." Plaque bears names of Secretary of Commerce Frederick Dent and Dr. Robert P. White, director of National Oceanic and Atmospheric Administration, who presented it to UC Pres. Charles J. Hitch. It is now displayed at Scripps Institution, location of UC's Institute of Marine Resources, which administers the UC Sea Grant College Program. Admiring plaque, from left, are Jeffery D. Frautschy, assistant director of Scripps and Sea Grant College program manager; Dr. George G. Shor, Jr., associate director of Scripps, who guided the Sea Grant program in its formative years; Prof. John D. Isaacs, director, Institute of Marine Resources; Scripps Dir. William A. Nierenberg; and Dr. James J. Sullivan, assistant Sea Grant program manager.

tratively housed in the statewide Institute of Marine Resources, and both are headquartered at Scripps. Policy guidance for the program is vested in the IMR Advisory Council; administrative advice and program review rests in the IMR Executive Subcommittee.

A small staff under Program Manager Jeffery D. Frautschy carries on the program's day-to-day management.

In its mission to maximize the wise utilization of the resources of the sea and defend against its hazards through research, education and

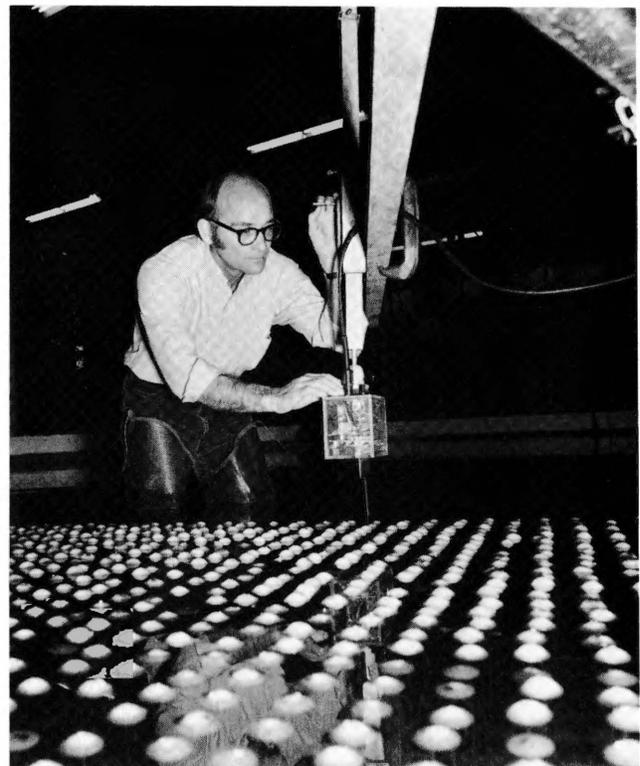
training, and public service, Sea Grant supports 43 projects and 66 trainees on California campuses. At Scripps, eight projects and 16 trainees were so supported. A full discussion of their accomplishments is published in the *UC Sea Grant Annual Report*; below are brief highlights of these eight projects. More detailed summaries are included elsewhere in this *SIO Annual Report*.

A program, "Ocean Education for the Public," under Donald W. Wilkie and through the facilities and staff of the Vaughan Aquarium-Museum, has involved 53,000 students in the group education program here and in San Diego County schools and hospitals. Teachers participated in in-service training on marine resources and fish physiology.

"Physical Criteria for Coastal Planning," under Dr. Douglas L. Inman, developed planning criteria for governmental agencies. Physical parameters of the shelf-and-shore environment have been and are being obtained with continuously recording instrument systems.

"Ecological Studies of the Nearshore Zone," under Dr. Paul K. Dayton, provides information to planning and regulatory agencies and to help harvesters. Monitoring of the La Jolla-San Diego Underwater Preserve was expanded and artificial-plant habitats were established.

"Mass culture of the Toxic Dinoflagellates," under Dr. Francis T. Haxo produces laboratory cultures for Dr. Henry Rapoport (UC-



During feasibility studies of tethered float breakwater system in Hydraulics Laboratory, then-graduate student Richard J. Seymour, who has since received his doctorate, adjusts wave-height measuring instrument. The wave-basin studies utilized 1,800 tethered, floating, foam-plastic spheres in a rectangular pattern of 30 rows in one direction and 60 rows parallel to man-made wave crests that diminished in size as waves moved past spheres toward simulated beach. Oscillation of spheres in an upside-down pendulum motion reduced energy of waves and, in turn, their size. Studies for the concept, which originated with John D. Isaacs, were funded by National Sea Grant College Program, California Department of Navigation and Ocean Development, and Foundation for Ocean Research. They have shown practicability of prototype installation that could use scores of floats attached to self-contained barges that are towed to a site and then flooded down to provide ballast for its complement of floats. The tethered float breakwater offers solution to problem of reducing locally the severity of wave climate where protection cannot be afforded by conventional means—in remote locations, in deep water, and in circumstances in which permanent protection is not desired.

Berkeley) in quest of a chemical test for saxitoxin, a toxin that at times renders shellfish inedible.

"Marine Resources Management Intern Research Program," under Dr. James J. Sullivan, has two interns, Michael Orbach and Tracy Lewis, engaged in fieldwork on tuna fishing communities and in simulating alternative management strategies.

"Marine Natural Products Chemistry," under Dr. D. John Faulkner, attempts to develop anti-fouling materials without toxic, heavy-metals compounds. Since bacteria seem to initiate fouling, six new antibiotics from marine organisms and one mechanism of bacterial autoinhibition have been described.

"Wave Climate Modification in Harbors by Dynamic Breakwaters," under John D. Isaacs, is aimed at low-cost alternatives for harbor, beach, and marina protection. Mathematical models and scaling laws were verified, and excellent attenuation of simulated random waves was obtained.

"Wave-Powered Generator," under Isaacs, seeks to provide power for buoys, and eventually on a commercial scale, from wind waves. A working model was tested at sea. In 5.4-m waves, the pump achieved a no-flow amplification of approximately nine times. The computer model can now predict the pump's performance in a random sea.

Isaacs has also proposed a new food web model in which a small number of trophic steps (classical model) gives way to pathways of food material so numerous and diverse that the web can be approached statistically, with a much simpler conceptualization of trophic positions, interactions, and trace element concentrations.

Additional Activities and Services

Twenty graduate students received IMR support for research related to the mission of the Institute. Two of the investigations culminated in dissertations; e. g., on the feeding ecology of an omnivorous copepod, and on the resistance of spheres in oscillatory flows. Abstracts of the dissertations and of the ongoing studies by students appear in the *IMR Biennial Report*, available from the Institute on request. That report also contains a listing of the *IMR Reference Series, q.v.*, and a listing of the *IMR Technical Report Series, q.v.*



Earl D. Bronson, CDR, USN (Ret.), at left, explains to Don Wilkie, director of Vaughan Aquarium-Museum, the many uses of ambergris, product of a sperm whale's digestive system. Ambergris is a superior fixative in fine perfumes, and is used in some cultures as a medical cure-all and love potion. Bronson donated 7½-pound sample to Aquarium-Museum.

SHORE FACILITIES AND COLLECTIONS

Facilities

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

The staff, assisted by nearly 80 volunteer docents, conducts a manifold educational program. More than 53,000 students annually tour the aquarium-museum in educational groups, and a career-experience program is offered to high school and college students considering an aquarium career. Special summer programs for grade-school students include a course titled "Skin Diving Natural History." Symposia for teachers are offered annually on marine topics of current interest. Federal Sea Grant funds support a full-time coordinator for educational programs.

Although admission is free, voluntary contributions from many of the more than 367,000 yearly visitors provide significant financial support.

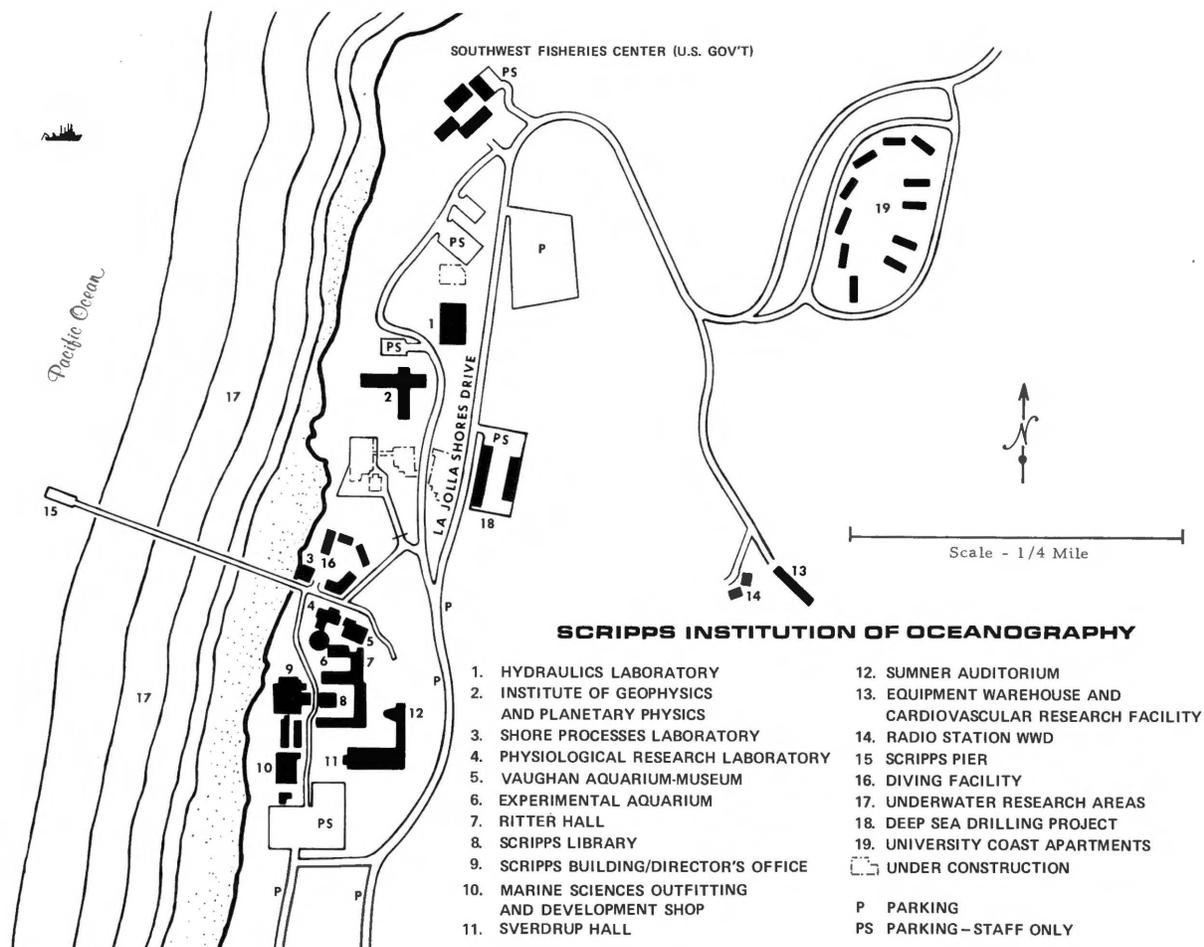
New museum exhibits, expansion of educational programs, and an exhibit designer are supported by gifts pledged to the Foundation for Ocean Research by the Southern California First National Bank for the benefit of the aquarium-museum.

Research is carried out on problems centering around maintenance systems for marine animals, coloration in fishes, and fish diseases. Several thousand specimens are collected annually for Scripps researchers and instructors. Research support is also provided through consultation.

The aquarium-museum is free and open to the public daily.

Experimental Aquarium (6). Used by faculty, research staff, and graduate students for various studies (such as fish culture), this aquarium is provided with seawater and is equipped with 5 rooms for controlled environmental studies, 17 tanks, and 8 seawater tables.

Marine Sciences Development Shop (10). This shop is equipped with precision tools and has a staff of toolmakers and diemakers who participate in the design, development, and fabrication of research equipment and instrumentation in support of the various laboratories at Scripps, the Southwest Fisheries Center—National Marine Fisheries Service, UCSD, the Scripps fleet, and other educational and governmental organizations throughout the United States.



Radio Station WWD (14). Licensed to the National Marine Fisheries Service and operated by Scripps personnel, Station WWD provides communications services to both organizations as well as to other governmental and institutional scientific ships. The station has worldwide capabilities. Voice, CW, radioteletype, and facsimile transmissions can be handled by the station, which operates 12 hours a day, Monday through Friday, and 8 hours a day on Saturday, Sunday, and holidays.

Scripps Library (8). The library houses a vast amount of oceanographic information with outstanding collections in oceanography, marine biology, and undersea technology. In addition to a basic collection of monographs and serials in mathematics, physics, chemistry, geology, and zoology, the main collection includes extensive expedition literature. As of June 30, 1974, the library held 102,796 bound volumes; 25,005 maps and charts; 20,611 reprints; 23,034 documents, reports, and translations; and 2,850 pieces of microcopy. The Documents/Reports/Translations Collection is comprised of a nucleus of technical reports and memoranda issued by Scripps and supplemented by reports and translations issued by other educational, governmental, and industrial institutions involved in marine research. The Map and Chart Collection is a reference collection of atlases, nautical charts, and geologic 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, as well as numerous accounts and journals of famous voyages of discovery.

Hydraulics Laboratory (1). This laboratory is equipped with a wind-wave channel 43x2.4x2.4m in size with a simulated beach and a tow cart for instrument and model towing; a 15x18-m wave basin with an adjustable simulated beach; a 40-m, glass-walled, wave-and-current channel; a granular fluid mechanics test facility consisting of a 6x12x3-m-deep concrete basin; a 10x1x1-m fluidizing channel; three sand storage and calibration tanks each 4 m high by 5 m in diameter, all serviced with a high-flow, slurry, pumping system; and an insulated, refrigerated, cylindrical seawater tank 10 m deep and 3 m in diameter used for various physical and biological studies. All wave generators in the laboratory are programmable and can be computer 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.

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, and pumps deliver the seawater used in laboratories and aquaria of Scripps and the Southwest Fisheries Center of the National Marine Fisheries Service.

Seawater System (15). The system provides seawater to Scripps and the Southwest Fisheries Center. It utilizes two sand filters and two concrete storage and settling tanks, each with a 200,568-ℓ capacity. Delivery capacity is 1,135 ℓ per minute.



Thomas O. Gettys, Marine Sciences Development Shop toolmaker and diemaker, mills steel for instrumentation to be used aboard one of Scripps's oceanographic research vessels. Design, development, and fabrication of much of Scripps's research equipment and instrumentation, including hardware for vessels, take place on campus in this shop.

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.

Diving Facility (16). The diving facility, which has easy access to the ocean, consists of two separate areas. One contains separate space for men's and women's showers, dressing rooms, and personal diving equipment storage. The second is devoted to air compressors, a 1,113-l air volume bank, diving cylinder storage, and an overhaul and repair facility. An 11-m diving boat and a 5-m skiff are available to the diving facility.

Scripps's SCUBA diver-training program, among the oldest diver-training and scientific diving programs in the country, conducts a number of SCUBA training classes annually. These are generally limited to University personnel who have the need to work or study underwater, but federal, state, and local government employees may be admitted by special permission. Some 100 faculty and staff members and students are certified for underwater work; they make an average of 4,000 dives a year. The Institution has a 12-year total of more than 55,000 accident-free dives.

Electron Microscope Laboratory (7). Two Siemens electron microscopes, together with freeze-etching (Balzers) and accessory equipment, provide high resolution in the study of ultra-fine structure.

Analytical Facility (11). The facility was organized four years ago to provide 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 1×10^{-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 mini-computer for data handling; carbon-dioxide analyzer for sample carbon and carbonate content in terms of carbon dioxide; scanning electron microscope for examination of samples at magnifications up to 100,000X enhanced by a depth of field far surpassing the light microscope. The facility offers complete sample preparation laboratories (including "wet" chemistry and rock processing laboratories, a table-top Olivetti computer, and geological field equipment).

Mass Spectrographic Equipment (7) and (11). Eight mass spectrometers are available, including two 15-cm, Nier-type spectrometers for isotopic analysis of light elements; a 15-cm, Nier-type spectrometer for rare gases; a 25.4-cm double-collection mass spectrometer for He³/He⁴ 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; and two units for respiratory gas analysis.

Underwater Research Areas (17). Located seaward off the campus is a marine research area set aside by the State of California. The taking of marine invertebrates and plants in this area is permitted only for scientific purposes. An adjoining ocean area is reserved by the Navy for Navy and Scripps research with bottom-mounted equipment. Both zones are now contained in the San Diego-La Jolla Underwater Park, which includes a completely protected "Look, Don't Touch" area. An underwater television camera located within the park transmits a signal to a monitor in the aquarium-museum, which allows visitors to observe typical inhabitants of an offshore reef as they carry out their daily activities.

Cardiovascular Research Facility (13). Established in 1965 as a joint enterprise of Scripps Institution's Physiological Research Laboratory and the Institute for Cardiopulmonary Diseases of Scripps Clinic and Research Foundation, La Jolla, this facility consists of an experimental animal colony and equipment for physiological research involving measurements of circulatory and cardiac functions in free-moving animals. This year Scripps Clinic provided additional laboratory space and



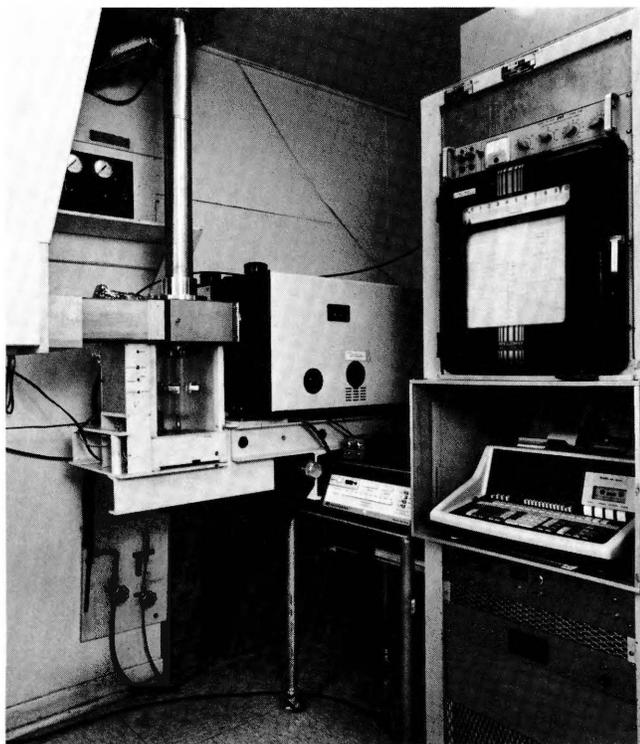
William J. Goff, Scripps librarian, uses model to explain design of proposed Scripps Library to staff members Barbara Tillett and Paul Leverenz. Groundbreaking for new \$3-million library is scheduled in spring of 1975; completion date is late in 1976. The three-story structure, with 31,993 square feet of assignable space, will be built north of Scripps's main complex of buildings, bounded on the west by Biological Grade and on the east by La Jolla Shores Drive.

equipment for a Cardiovascular Instrumentation Development Laboratory in support of its physiological research.

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.

Mt. Soledad Laboratory for Marine Radioactivity Studies (Two miles south of Scripps campus). This laboratory, because of its highly specialized equipment and its isolation from other research areas where relatively large amounts of radioactivity are employed, provides 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 of its 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.

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



Specialized flame spectrometer built at Mt. Soledad Laboratory for Marine Radioactivity Studies is utilized to investigate distribution in the ocean of extremely small traces of the natural alkali metal, cesium. By using this precise equipment, scientists found that distribution varied no more than 1.5 percent anywhere in northeast Pacific Ocean, from its surface to the bottom. These data, useful in support of studies of fallout radiocesium, also suggest state of equilibrium of this rare alkali on geochemical scales. Operations are controlled by small digital computer (at right), which also computes immediately the analytical results and evaluates their statistical merits.

California Natural Land and Water Reserve System. Surrounding tidal and shoal waters have been designated by the City of San Diego to be retained in a natural condition. The reserve has been used frequently for teaching and research by UCSD and other California colleges, and a laboratory has been planned and funded to facilitate further use of the area.

San Vicente Lake Calibration Facility (30 miles northeast of San Diego). This facility, operated by the Marine Physical Laboratory, is equipped for testing and calibrating acoustic transducers used in oceanographic research. The equipment is located on an 8x15-m enclosed platform in 40 m of water, offering 1,372 m of unobstructed range.

Shipboard Computer Group (7). This group of computer programmers, engineers, and technicians supports four IBM 1800 computers and, as required, other computer systems at Scripps through programming, interface design, and maintenance. Computers are installed permanently on R/V *Thomas Washington* and R/V *Melville* and ashore in Ritter Hall.

The 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 a 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 probe), XBT (Expendable Bathothermograph), 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.

Shore Processes Laboratory (3). The Shore Processes Laboratory is the research facility utilized by the Shore Processes Study Group, whose principal interest is the investigation of the nearshore environment. The structure, a 3,000-square-foot, multipurpose building, includes office, laboratory, and shop space. An electronics laboratory and mechanical shop within the building are used for fabricating and maintaining instrumentation. The laboratory houses data acquisition and processing equipment, including 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 computer equipped with a disk storage unit, digital tape recorders, a paper tape recorder, and CRT terminal. The laboratory includes a library that contains an extensive collection of reference material on coastal zone processes.

Special Collections

Geologic Data Center (5). Geologic data collected by Scripps vessels are cataloged and stored at this location. Index charts have been made for several hundred thousand nautical miles of expedition tracks through all sectors of the Pacific Ocean and part of the Arctic Ocean. Also available are overlays of the bathymetry, magnetic anomalies, and seismic reflection profiles and refraction stations. The original seismic reflection profiles are recorded on microfilm. Colored charts of the bathymetry and sediments of the North Pacific may be ordered from the Institute of Marine Resources. The originals are at a 1:3,000,000 scale and are kept at the Geologic Data Center, where they are displayed and continually updated.

Marine Vertebrates (Fish Collection, 5 and 7). More than 2,500 cataloged species of marine fishes and in excess of one million specimens are in this collection. Added in Fiscal 1974 were 600 collections of bathypelagic and shore fishes.

Marine Invertebrates (Zooplankton Collection, 7). In this collection are nearly 55,000 zooplankton samples; of these more than 20,000 are from special expeditions and some 1,150 from Isaacs-Kidd mid-water trawls. Samples are supplemented by full meteorological, hydrographic, physical, and chemical data.

Geological Samples (Storage locker is across from Diving Facility). This collection has more than 4,000 deep-sea sediment cores, which are kept under refrigeration. It also contains rocks and manganese nodules collected mainly from the Pacific and Indian oceans. These materials are available for study by scientific investigators; students may have access to the cores.

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.

Oceanographic Data Archive (11). This collection includes more than 500,000 Pacific and Indian ocean bathythermograph observations taken since 1941, tide-gauge records taken since 1925 at Scripps Pier, and daily temperature and salinity records from southern California shore stations taken since 1916. Summaries of the shore station data, issued annually, are available upon request.



Marine technician on R/V *Alexander Agassiz* attaches a clamp which holds a bongo net frame. Bongo net is towed to collect samples of vertical distribution of plankton.

PUBLICATIONS

Introduction

The research being conducted at Scripps Institution of Oceanography is reflected in the publications of the faculty and staff. These publications, for the most part, are highly technical and range from short internal data reports to long genus revisions. Scripps publications are generally distributed by subscription, exchange, or military contracts.

Below are listed the various Scripps Institution of Oceanography publications for 1973-1974, including information on their availability.

Bulletin

The *Scripps Institution of Oceanography Bulletin*, which contains lengthy papers by the faculty and staff, is the only Scripps publication available by subscription. For information about subscriptions and a list of those numbers available, please write: The University of California Press, 2223 Fulton Street, Berkeley, California 94720.

Note: There were no volumes of the bulletin published during 1973-1974.

Contributions

This publication is a compilation of selected reprints authored by the Scripps faculty and staff. The *Scripps Institution of Oceanography Contributions* is published annually and available only on an exchange basis. For information concerning exchanges, please write: Gift and Exchange Department, Library, University of California, San Diego, P.O. Box 2367, La Jolla, California 92037.

The articles listed below may be found in the publications cited. Information about specific reprints may be obtained by writing directly to the author in care of: Scripps Institution of Oceanography, P. O. Box 1529, La Jolla, California 92037.

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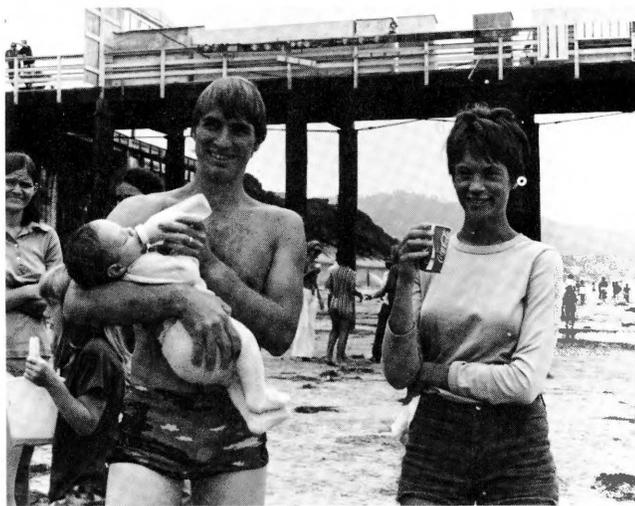
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This isn't Cooney Island in August . . . just part of the Institution's "family" enjoying the annual Scripps beach outing, complete with hot fish chowder, cold drinks, foot races, a swimming race around the 1,000-foot Scripps Pier, and time out for lunch for young Ryan Johnson, held by his father, Tom, a graduate student in geology, and a Coke for his mother, Chris.

Tom Walsh

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Off-duty hours on *Tasaday XI* aboard the *Thomas Washington* often brought folk music by the "Fantail Philharmonic," under the direction of graduate student Harold W. Lyons, shown on guitar (center) and on harmonica (upper right), with Dr. William G. Harrison on kazoo. Dr. Michael M. Mullin (upper left) plays brass slide whistle, which was turned on ship's lathe by graduate student Eric Shulenberger. Graduate student Karen Wishner strokes "Olycans" for percussion, and Dr. Richard W. Eppley plucks strings on "gut bucket" made from a strip of wood, a 5-gallon can, and nylon cord used for closure mechanism for Niskin bottles. All the musicians are Scripps scientists in biological oceanography.

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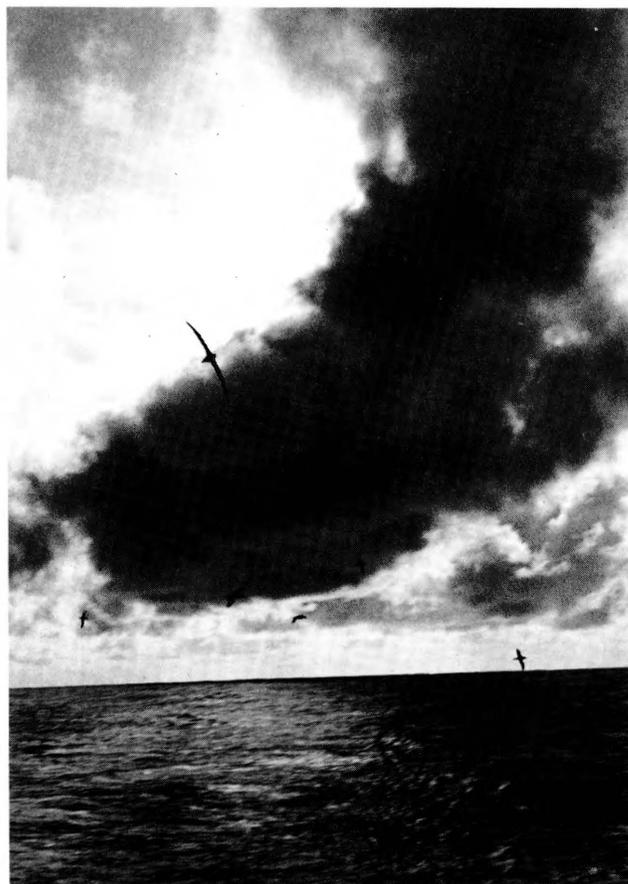


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Robert L. Fisher	Geological Research Division	Marine Geology
Raymond W. Fitzgerald	Geological Research Division	X-ray Physics
Arthur O. Flechsig	Ocean Research Division	Biological Oceanography
Abraham Fleminger	Marine Life Research Group	Marine Biology
Theodore R. Folsom	Ocean Research Division	Physical Oceanography
Theodore D. Foster	Marine Physical Laboratory/ Ocean Research Division	Physical Oceanography
*Denis L. Fox	Marine Biology Research Division	Marine Biology
Jeffery D. Frautschy	Scientific Support Division/ Sea Grant College Program	Marine Technology
Jane Zaiser Frazer	Geological Research Division	Numerical Analysis
Carl A. Friehe	AMES/Advanced Ocean Engineering Laboratory/Ocean Research Division	Ocean Turbulence
Walter F. Garey	Physiological Research Laboratory	Physiology
Carl H. Gibson	AMES/Sea Grant College Program	Fluid Dynamics
Joris M. T. M. Gieskes	Ocean Research Division	Marine Chemistry
J. Freeman Gilbert	Institute of Geophysics and Planetary Physics	Geophysics
Bjorn Gjevik	Institute of Geophysics and Planetary Physics	Physical Oceanography
Edward D. Goldberg	Geological Research Division	Chemistry
Fritz W. Goro	Marine Biology Research Division	Marine Biology
Michael C. Gregg	Advanced Ocean Engineering Laboratory	T-S Microstructure
John J. Griffin	Geological Research Division	Mineralogy
Nicolas Grijalva	Ocean Research Division	Physical Oceanography
Edwin L. Hamilton	Geological Research Division	Geophysics
Harold T. Hammel	Physiological Research Laboratory	Physiology
James L. Harris	Visibility Laboratory	Optical Physics
William G. Harrison	Institute of Marine Resources	Marine Ecology
Peter H. Hartline	Neurobiology Unit	Neurobiology
Richard A. Haubrich	Institute of Geophysics and Planetary Physics	Geophysics
Loren R. Haury	Marine Biology Research Division	Biology
James W. Hawkins	Geological Research Division	Geology
Francis T. Haxo	Marine Biology Research Division	Marine Botany
Walter F. Heiligenberg	Ocean Research Division	Behavioral Physiology
Edvard A. Hemmingsen	Physiological Research Laboratory	Physiology
Myrl C. Hendershott	Ocean Research Division	Physical Oceanography
Anita Young Hessler	Marine Biology Research Division	Biology
Robert R. Hessler	Marine Life Research Group/ Marine Biology Research Division	Biological Oceanography
†Jed Hirota	Institute of Marine Resources	Biological Oceanography
Edmund S. Hobson	Marine Biology Research Division	Marine Biology
Vernon F. Hodge	Ocean Research Division	Chemistry
Nicholas D. Holland	Marine Biology Research Division	Marine Biology
Osmund Holm-Hansen	Institute of Marine Resources	Marine Biology
R. Barry Holtz	Marine Biology Research Division	Biochemistry
Carl Hopkins	Neurobiology Unit	Neurobiology
†Yoshio Horibe	Geological Research Division	Chemistry
Joseph C. K. Huang	Ocean Research Division	Physical Oceanography
*Carl L. Hubbs	Marine Biology Research Division	Marine Biology
Kuni Pfeffer Hulsemann	Marine Life Research Group	Zooplankton Taxonomy
John P. Hunt	Institute of Marine Resources	Earth Resources
°John R. Hunter	Department SIO	Ichthyology
John M. Huthnance	Institute of Geophysics and Planetary Physics	Geophysics
Douglas L. Inman	Ocean Research Division	Physical Oceanography

John D. Isaacs	Institute of Marine Resources/ Marine Life Research Group	Oceanography
*Martin W. Johnson	Marine Life Research Group	Marine Biology
James Joseph	Institute of Marine Resources	Marine Biology
Joseph W. Joy	Advanced Ocean Engineering Laboratory/ Ocean Research Division	Oceanography
Adrianus J. Kalmijn	Neurobiology Unit	Neurobiology
Daniel E. Karig	Deep Sea Drilling Project	Geophysics
Harvey J. Karten	Neurobiology Unit	Neurobiology
Miriam Kastner	Geological Research Division	Geology
Charles D. Keeling	Ocean Research Division	Marine Chemistry
Charlotte Davidson Keen	Department SIO	Geophysics
George J. Kenagy	Physiological Research Laboratory	Zoology
Kern E. Kenyon	Ocean Research Division	Physical Oceanography
Dale A. Kiefer	Institute of Marine Resources	Biological Oceanography
George D. Klein	Deep Sea Drilling Project	Geology
Stanley A. Kling	Marine Life Research Group	Paleontology
Margaret D. Knight	Marine Life Research Group	Biological Oceanography
Robert A. Knox	Ocean Research Division/Advanced Ocean Engineering Laboratory	Oceanography
Minoru Koide	Geological Research Division	Marine Chemistry
Gerald L. Kooyman	Physiological Research Laboratory	Physiology
Devendra Lal	Geological Research Division	Nuclear Geophysics
Ronald K. Lam	Institute of Marine Resources	Oceanography
G. David Lange	Neurobiology Unit	Neurobiology
Robberd E. Lange	Advanced Ocean Engineering Laboratory	Physical Oceanography
°Reuben Lasker	Department SIO	Marine Biology
Michael Laurs	Institute of Marine Resources	Oceanography
Richard F. Lee	Marine Biology Research Division	Biochemistry
David L. Leighton	Sea Grant Program	Marine Biology
Ralph A. Lewin	Marine Biology Research Division	Marine Biology
Leonard N. Liebermann	Physics/Marine Physical Laboratory	Physics
Yuan (DeVries) Lin	Physiological Research Laboratory	Physiology
†Peter S. Liss	Geological Research Division	Chemical Oceanography
Cinna Lomnitz	Geological Research Division	Geophysics
Ralph H. Lovberg	Physics/Institute of Geophysics and Planetary Physics	Physics
Carl D. Lowenstein	Marine Physical Laboratory	Marine Physics
John E. Lupton	Geological Research Division	Physics
Timothy H. Mague	Institute of Marine Resources	Biology
Paul I. Mandell	Institute of Marine Resources/ Center for Marine Affairs	Geography
Arnold Mantyla	Marine Life Research Group/ Ocean Research Division	Oceanography
Monte C. Marshall	Deep Sea Drilling Project	Geology
Tetsuo Matsui	Marine Life Research Group	Biological Oceanography
Jerry L. Matthews	Geological Research Division	Geology
Edward D. McAlister	Marine Physical Laboratory	Physics
†Robert N. McDonough	Marine Physical Laboratory	Engineering
John A. McGowan	Marine Life Research Group	Biological Oceanography
Charles W. Mehard	Marine Biology Research Division	Biochemistry
Henry W. Menard	Geological Research Division/ Institute of Marine Resources	Geology
Charles J. Merdinger	Deputy Director	Civil Engineering
Dietrich L. Meyers	Neurobiology Unit	Neurobiology
John W. Miles	AMES/Institute of Geophysics and Planetary Physics	Geophysics/Fluid Dynamics
Stephen P. Miller	Marine Physical Laboratory	Geophysics
Peter H. Molnar	Institute of Geophysics and Planetary Physics	Geophysics
David G. Moore	Geological Research Division	Geology
George W. Moore	Geological Research Division	Geology
Kenneth R. Morgareidge	Physiological Research Laboratory	Comparative Physiology
Gerald B. Morris	Marine Physical Laboratory	Geophysics
John D. Mudie	Marine Physical Laboratory/ Geological Research Division	Geophysics
Peta Jane Mudie	Institute of Marine Resources	Botany
Michael M. Mullin	Institute of Marine Resources	Biological Oceanography
Walter Munk	Institute of Geophysics and Planetary Physics/ Ocean Research Division	Geophysics
Jerome Namias	Ocean Research Division	Long-Range Weather Forecast/ Ocean Atmosphere Interaction
Kenneth H. Neelson	Marine Biology Research Division	Microbiology

Judd C. Nevenzel William A. Newman William A. Nierenberg Charles E. Nordstrom William R. Normark Benton B. Owen Frances L. Parker Robert L. Parker	Marine Biology Research Division Scientific Support Division Director Ocean Research Division Marine Physical Laboratory Marine Physical Laboratory Geological Research Division Institute of Geophysics and Planetary Physics/ Ocean Research Division Marine Life Research Group Deep Sea Drilling Project/ Geological Research Division Geological Research Division Deep Sea Drilling Project Institute of Geophysics and Planetary Physics Ocean Research Division Institute of Marine Resources Marine Physical Laboratory Ocean Research Division Ocean Research Division Marine Physical Laboratory Marine Physical Laboratory Center for Marine Affairs Institute of Marine Resources Marine Life Research Group Director Emeritus Scientific Support Division Institute of Marine Resources Ocean Research Division Marine Biology Research Division Geological Research Division	Biochemistry Biological Oceanography Physics Geology Geology Chemistry Paleontology Geophysics
William C. Patzert M. N. A. Peterson	Marine Life Research Group Deep Sea Drilling Project/ Geological Research Division Geological Research Division Deep Sea Drilling Project Institute of Geophysics and Planetary Physics Ocean Research Division Institute of Marine Resources Marine Physical Laboratory Ocean Research Division Marine Physical Laboratory Marine Physical Laboratory Center for Marine Affairs Institute of Marine Resources Marine Life Research Group Director Emeritus Scientific Support Division Institute of Marine Resources Ocean Research Division Marine Biology Research Division Geological Research Division	Oceanography Marine Geology
Fred B Phleger Anthony C. Pimm William A. Prothero	Marine Physical Laboratory Institute of Marine Resources Marine Physical Laboratory Ocean Research Division Ocean Research Division Marine Physical Laboratory Marine Physical Laboratory Center for Marine Affairs Institute of Marine Resources Marine Life Research Group Director Emeritus Scientific Support Division Institute of Marine Resources Ocean Research Division Marine Biology Research Division Geological Research Division	Oceanography Geology Geophysics
Reiner R. R. Protsch Anne Heuser Radlow Russell W. Raitt *Norris W. Rakestraw Marilyn Ramenofsky Robert A. Rasmussen Stephen D. Rearwin Michael L. Redfield Freda Hunt Reid Joseph L. Reid *Roger R. Revelle William R. Riedel Robert W. Risebrough Margaret K. Robinson Richard H. Rosenblatt Peter H. Roth	Marine Physical Laboratory Institute of Marine Resources Geological Research Division Scientific Support Division Marine Life Research Group Marine Physical Laboratory Physiological Research Laboratory Marine Life Research Group Marine Physical Laboratory Geological Research Division Institute of Marine Resources Institute of Marine Resources Geological Research Division Geological Research Division/ Marine Physical Laboratory/ Sea Grant College Program Institute of Marine Resources Visibility Laboratory Scientific Support Division Geological Research Division Visibility Laboratory Geological Research Division Institute of Geophysics and Planetary Physics Scientific Support Division Marine Biology Research Division Marine Life Research Group Marine Physical Laboratory Center for Marine Affairs Marine Biology Research Division Advanced Ocean Engineering Laboratory/Ocean Research Division Ocean Research Division Advanced Ocean Engineering Laboratory Geological Research Division Marine Biology Research Division Sea Grant College Program	Anthropology Botany Marine Geophysics Marine Chemistry Endocrinology Marine Physics Physics Marine Law Taxonomy Physical Oceanography Marine Geology Marine Geology Biology Physical Oceanography Marine Zoology Nannofossil Micro- paleontology Physics Biochemical Oceanography Paleontology Biological Oceanography Marine Resources Geophysics Marine Physiology Physical Oceanography Geophysics Biology Oceanography Biology Submarine Geology Marine Geophysics
Philip Rudnick Egil Sakshaug Annika Berggren Sanfilippo Marston C. Sargent Walter R. Schmitt Manfred Schober *Per F. Scholander Richard A. Schwartzlose John G. Sclater Edward D. Scura Richard J. Seymour Jonathan H. Sharp *Francis P. Shepard George G. Shor, Jr.	Marine Physical Laboratory Institute of Marine Resources Geological Research Division Scientific Support Division Marine Life Research Group Marine Physical Laboratory Physiological Research Laboratory Marine Life Research Group Marine Physical Laboratory Geological Research Division Institute of Marine Resources Institute of Marine Resources Geological Research Division Geological Research Division/ Marine Physical Laboratory/ Sea Grant College Program Institute of Marine Resources Visibility Laboratory Scientific Support Division Geological Research Division Visibility Laboratory Geological Research Division Institute of Geophysics and Planetary Physics Scientific Support Division Marine Biology Research Division Marine Life Research Group Marine Physical Laboratory Center for Marine Affairs Marine Biology Research Division Advanced Ocean Engineering Laboratory/Ocean Research Division Ocean Research Division Advanced Ocean Engineering Laboratory Geological Research Division Marine Biology Research Division Sea Grant College Program	Biochemical Oceanography Applied Physics Marine Engineering Mineralogy Physics Submarine Geology Geophysics
Roelant J. Siezen Donald E. Silva †Maxwell Silverman John Sinkankas Raymond C. Smith Stuart M. Smith Frank E. Snodgrass	Marine Physical Laboratory Institute of Marine Resources Geological Research Division Scientific Support Division Marine Life Research Group Marine Physical Laboratory Center for Marine Affairs Marine Biology Research Division Advanced Ocean Engineering Laboratory/Ocean Research Division Ocean Research Division Advanced Ocean Engineering Laboratory Geological Research Division Marine Biology Research Division Sea Grant College Program	Biochemical Oceanography Applied Physics Marine Engineering Mineralogy Physics Submarine Geology Geophysics
James M. Snodgrass George N. Somero Andrew Soutar Fred N. Spiess J. Ronald Stanfield Joan Godsil Stewart Robert H. Stewart	Marine Physical Laboratory Institute of Marine Resources Geological Research Division Scientific Support Division Marine Life Research Group Marine Physical Laboratory Center for Marine Affairs Marine Biology Research Division Advanced Ocean Engineering Laboratory/Ocean Research Division Ocean Research Division Advanced Ocean Engineering Laboratory Geological Research Division Marine Biology Research Division Sea Grant College Program	Electronic Instrumentation Marine Biology Paleontology Marine Physics Economics Biology Oceanography
Charles K. Stidd Denzil Stilwell Chih-wu Su Cornelius W. Sullivan James J. Sullivan	Marine Physical Laboratory Institute of Marine Resources Geological Research Division Scientific Support Division Marine Life Research Group Marine Physical Laboratory Center for Marine Affairs Marine Biology Research Division Advanced Ocean Engineering Laboratory/Ocean Research Division Ocean Research Division Advanced Ocean Engineering Laboratory Geological Research Division Marine Biology Research Division Sea Grant College Program	Meteorology Physics Organic Chemistry Microbiology Economics

Peter R. Supko	Deep Sea Drilling Project	Marine Geology
Bruce A. Taft	Marine Life Research Group	Physical Oceanography
†Rita Falk Taubenfeld	Center for Marine Affairs	Environmental Economy
Wayne R. Thatcher	Institute of Geophysics and Planetary Physics	Geophysics
William H. Thomas	Institute of Marine Resources	Microbiology
†Dale W. Toetz	Institute of Marine Resources	Biology
Mizuki Tsuchiya	Institute of Marine Resources	Biological Oceanography
John E. Tyler	Visibility Laboratory	Physics
Victor Vacquier	Marine Physical Laboratory	Geophysics
Tracy L. Vallier	Deep Sea Drilling Project	Geology
Charles W. Van Atta	AMES/Sea Grant College Program	Geophysical Fluid Dynamics
William G. Van Dorn	Ocean Research Division/ Advanced Ocean Engineering Laboratory	Physical Oceanography
Mahalakshmi Venkatesan	Ocean Research Division	Organic Chemistry
Elizabeth L. Venrick	Marine Life Research Group	Biology
Benjamin E. Volcani	Marine Biology Research Division	Marine Microbiology
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
Thomas W. Whitaker	Marine Biology Research Division	Marine Biology
Warren B. White	Ocean Research Division	Oceanography
Gerald L. Wick	Institute of Marine Resources/ Center for Marine Affairs	Physics
Donald W. Wilkie	Aquarium-Museum	Marine Biology
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
Edward L. Winterer	Geological Research Division	Geology
Jacqueline Mammerickx	Geological Research Division	Geology
Winterer		
Warren S. Wooster	Center for Marine Affairs/ Ocean Research Division	Physical Oceanography
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

‡Deceased

Appendix A

DIRECTOR—DEAN
W. A. Nierenberg

DEPUTY DIRECTOR
C. J. Merdinger

ASSOCIATE DIRECTORS
R. L. Fisher
W. S. Levin
G. G. Shor, Jr.
F. N. Spiess

ASSISTANT DIRECTOR
J. D. Frautschy

INSTRUCTION

GRADUATE DEPARTMENT OF THE SCRIPPS
INSTITUTION OF OCEANOGRAPHY
J. R. Curray, Chairman
M. M. Mullin, Vice-Chairman

APPLIED OCEAN SCIENCES
V. C. Anderson

BIOLOGICAL OCEANOGRAPHY
J. T. Enright

GEOPHYSICS
R. L. Parker

MARINE BIOLOGY
R. A. Lewin

MARINE CHEMISTRY
G. Arrhenius

GEOLOGICAL SCIENCES
J. W. Hawkins

PHYSICAL OCEANOGRAPHY
R. S. Arthur

SHIP OPERATIONS AND MARINE TECHNICAL SUPPORT

MARINE FACILITIES
P. S. Branson

MARINE TECHNOLOGY GROUP
J. L. Abbott

RESEARCH DIVISION

GEOLOGICAL RESEARCH
J. N. Brune

MARINE BIOLOGY RESEARCH
F. T. Haxo

OCEAN RESEARCH
C. S. Cox

RESEARCH GROUPS

ADVANCED OCEAN
ENGINEERING LABORATORY
G. H. Fisher

DEEP SEA DRILLING
M. N. A. Peterson

MARINE LIFE RESEARCH
J. D. Isaacs

MARINE PHYSICAL LABORATORY
F. N. Spiess

NEUROBIOLOGY UNIT
T. H. Bullock
PHYSIOLOGICAL RESEARCH LABORATORY
A. A. Benson

VISIBILITY LABORATORY
S. Q. Duntley

RESEARCH SUPPORT

AQUARIUM-MUSEUM
D. L. Wilkie

CENTRAL SHOPS AND
SPECIAL SERVICES
G. L. Matson

ASSOCIATED RESEARCH

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

INSTITUTE OF MARINE RESOURCES
J. D. Isaacs, Director
Tuna Oceanography Research
Group
Food Chain Research Group
Sea Grant College Office
Center for Marine Affairs

OTHER SUPPORT

LIBRARY
W. J. Goff

PHOTOGRAPHIC LABORATORY
L. D. Ford

PUBLIC AFFAIRS
R. N. Fuller

Appendix B SPONSORS OF RESEARCH AND GRADUATE INSTRUCTION

STATE:

Human Resources Development
Department of Fish and Game
Department of Navigation and Ocean Development

FEDERAL:

Atomic Energy Commission
Environmental Protection Agency
National Aeronautics and Space Administration
National Science Foundation
Department of the Air Force
Department of the Army
Corps of Engineers
Department of Commerce
National Oceanic and Atmospheric Administration
National Advisory Committee on Oceans and Atmosphere
National Marine Fisheries Service
Department of Defense
Advanced Research Projects Agency
Department of Health, Education and Welfare
Department of the Interior
Fish and Wildlife Service
Geological Survey
Department of the Navy

OTHER:

American Chemical Society
American Heart Association
Alcoa Foundation
American Optical Corporation
ARCS Foundation
Ellen Browning Scripps Endowment Fund
M. C. Fleischmann Foundation
Wm. L. Dowd Memorial

Dupont
Ford Foundation
Foundation for Ocean Research
Griffis Foundation
International Nickel Company
Kennecott Copper Corporation
Kennecott Exploration, Inc.
La Jolla Foundation for Earth Sciences
L. S. B. Leakey Foundation
Lieberman Lectures
John B. McKee Fund
National Academy of Sciences
National Center for Atmospheric Research
National Geographic Society
Navy League of San Francisco (Chester W. Nimitz Fund)
Occidental Petroleum
Peterson-Silberman Fund
Population Council
Rockefeller Foundation
G. D. Searle and Company
Francis P. Shepard Foundation
A. P. Sloan Foundation
Seth Sprague Foundation
U. S. Steel
Scripps Industrial Associates
AGIP
AMOCO International Oil Company
Atlantic Richfield Company
Chevron Oil Field Research Company
Continental Oil Company
EXXON Production Research Company
Gulf Oil Corporation
Metellgesellschaft A.G.
Mobil Oil Corporation
Shell Oil Company
Société Nationale Des Pétroles d'Aquitaine
Sun Oil Company
Texaco, Incorporated
Union Oil Company

Appendix C MAJOR AWARDS AND HONORS

Earl D. Bronson
Cited by Oceanographer of the United States Navy.
Dr. Carl H. Eckart
Received posthumously the Pioneers of Underwater Acoustics Medal from the Acoustical Society of America.
Dr. Carl L. Hubbs
Named "Scientist of the Year" by the San Diego Society of Natural History. Received outstanding conservation award from the National Underwater Parks and Reserves Association.
John D. Isaacs
Elected to membership in the National Academy of Sciences.
Dr. William A. Nierenberg
Appointed member, Joint U.S.-U.S.S.R. Committee for the U.S.-U.S.S.R. Agreement for Cooperative Studies of the World Ocean. Appointed a United States Delegate to the United Nations Conference on the Law of the Sea (Caracas Session).
Dr. Per F. Scholander
Received Honorary Doctor of Science, University of Alaska.
Dr. Frank E. Snodgrass
Named first recipient of the Institute of Electrical and Electronic Engineers' award for ocean engineering achievements.
Dr. Fred N. Spiess
Presented the Capt. Robert Dexter Conrad Award of the U.S. Navy.



Rear Adm. M. D. Van Orden, USN, Chief of Naval Research, right, presents the Capt. Robert Dexter Conrad Award, Navy's highest award for scientific achievement, to Scripps Assoc. Dir. Fred N. Spiess, director of the Marine Physical Laboratory, as Mrs. Spiess looks on. The Conrad Award went to Dr. Spiess "for (his) outstanding achievement in the planning, conducting, and administration of research and development, particularly in the area of ocean environmental research." On July 1, 1974, Dr. Spiess began 15-months' leave from Scripps to serve on the scientific staff of the London branch of the Office of Naval Research.



Dr. Melvin N. A. Peterson, at right, manager of Deep Sea Drilling Project (DSDP), describes deep-sea core sample to astronaut Robert L. Crippen, LCDR, USN, of National Aeronautics and Space Administration, at DSDP headquarters. Looking on, from left are Dr. Carl L. Hubbs, professor of biology emeritus, and Dr. N. Terence Edgar, chief scientist of DSDP. Commander Crippen visited Scripps as guest of Dr. Hubbs, who was honored that evening at the centennial anniversary dinner of San Diego Society of Natural History as Society's "Scientist of the Year." Commander Crippen was featured speaker at the dinner.



Dr. Fred N. Spiess, director of the Marine Physical Laboratory (MPL), at left, congratulates Earl D. Bronson, LCDR, USN (Ret.), who retired during the year, for receiving citation from Oceanographer of the Navy, Rear Adm. J. Edward Snyder, Jr., for his outstanding service to the Navy as marine coordinator for MPL.

Appendix D

RESEARCH VESSELS OF SCRIPPS INSTITUTION OF OCEANOGRAPHY

	Alexander Agassiz	Alpha Helix	Dolphin	Melville	Oconostota	Ellen B. Scripps	Thomas Washington	FLIP	ORB
Type:	light freight	oceanographic research (biological)	oceanographic research	oceanographic research	tug	offshore supply	oceanographic research	floating instrument platform	oceanographic research buoy
Hull:	steel	steel	aluminum	steel	steel	steel	steel	steel	steel
Year Built:	1944	1965-1966	1968	1969	1944	1964-1965	1965	1962	1968
Year acquired by SIO:	1961	1966	1973	1969	1962	1965	1965	1962	1968
From whom acquired:	State Educational Agency for Surplus Property	National Science Foundation	Robert O. Peterson	U.S. Navy	U.S. Navy	Dantzer 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	U.S. Navy	University of California	U.S. Navy	U.S. Navy	U.S. Navy
Length:	180'	133'	96'	245'	102'	95'	209'	355'	69'
Beam:	32'	31'	22'	46'	25'	24'	40'	20'/12'	45'
Draft:	10'	10'5½"	8'6"	15'	10'	6'	14'	10'/300'	fwd. 4'10½" aft 5'4½"
Displacement: Tons (full):	869	512	96.09	1,915	206	115	1,362	2,100 (vertical)	299.5
Maximum speed:	11	10.5	14	12	11	9	12.5	varies ⁻¹	varies ⁻¹
Minimum speed:	0-1	0-3	0-3	0-1	0-1	1	0-1	varies ⁻¹	varies ⁻¹
Range (miles):	5,940	6,200	2,000	9,840	4,500	6,480	8,700	varies ⁻¹	varies ⁻¹
Endurance (days):	22	30	7	41	16	30	29	varies ⁻¹	30
Crew:	18	12	5	25	8	5	25	5	5
Scientific party:	13	12	8	25	6	8	17	11	12

⁻¹Depends on towing vessel
 1973-74 TOTAL DAYS AT SEA: 1,215
 1973-74 NAUTICAL MILES STEAMED: 147,979

Appendix E
DOCTOR OF PHILOSOPHY DEGREES
AWARDED IN 1973-74
WITH TITLES OF DISSERTATIONS

Marine Biology

Edgardo D. Gomez, "The Biology of the Commensal Barnacle *Balanus galeatus* (L) with Special Reference to the Complementary Male-Hermaphrodite Relationship"

Eric O. Hartwig, "Physical, Chemical and Biological Aspects of Nutrient Exchange Between the Marine Benthos and the Overlying Water."

Robert R. Warner, "Ecological and Evolutionary Aspects of Hermaphroditism in the California Sheephead, *Pimelometopon pulchrum* (Ayers)."

(Sequential hermaphroditism is the normal pattern of sexual development in the sheephead, with all individuals first functioning as females then transforming to males. This strategy insures maximum reproductive potential for each individual.)

Arthur A. Wolfson, "Some Effects of Increased Temperature on the Settlement and Developments of a Marine Community in the Laboratory."

(Some biological effects of elevated temperature characteristic of the regime created by the discharge of thermal effluent from coastal power plants were studied in the laboratory under controlled environmental conditions. Thermal addition had significant effects on settlement, growth, reproduction, and survival of marine epifauna.)

Oceanography

Arthur M. Barnett, "The Feeding Ecology of an Omnivorous Neritic Copepod, *Labidocera trispinosa* Esterly"

James L. Cairns, "Internal Wave Measurements from a Midwater Float"

(Properties of internal waves of mid-depths have been studied by means of a yo-yoing capsule. The spectra are reproducible and show a sharp cutoff beyond the Brunt-Väisälä frequency.)

Gregory F. Dreyer, "Comparison of Momentum, Sensible and Latent Heat Fluxes over the Open Ocean Determined by the Direct Covariance, Inertial, and Direct Dissipation Techniques"

Loren R. Haury, "Studies on the Sampling and Small-Scale Pattern of Marine Zooplankton"

Robherd E. Lange, "Decay of Turbulence in Stratified Salt Water"

Richard J. Seymour, "Resistance of Spheres in Oscillatory Flows"

MASTER OF SCIENCE DEGREES
AWARDED IN 1973-74

Oceanography

Tarsicio J. Antezana

James A. Bailard

J. Wayne Hill

Stephen P. Kline

Dudley W. Leath

Jeffrey D. Rude

Kin H. Tsang

Earth Sciences

Robert M. Cutler

James A. Bailard

David A. Yuen

Marine Biology

Sophia Fei Hu

Appendix F
REGENTS AND OFFICERS
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.

George H. Link

President of the Alumni Association of the University of California.

Edward A. Morris

Vice President of the Alumni Association of the University of California.

Charles J. Hitch

President of the University.

APPOINTED REGENTS

Edward W. Carter

Mrs. Randolph A. Hearst

Norton Simon

William E. Forbes

William M. Roth

Mrs. Edward H. Heller

Frederick G. Dutton

William K. Coblentz

DeWitt A. Higgs

Glenn Campbell

William French Smith

Robert O. Reynolds

Dean A. Watkins

John H. Lawrence, M. D.

William A. Wilson

Joseph A. Moore, Jr.

REGENT DESIGNATE

James Collins

PRINCIPAL OFFICERS OF THE REGENTS

Donald L. Reidhaar

General Counsel.

Owsley B. Hammond

Treasurer.

Marjorie J. Woolman

Secretary.

OFFICE OF THE PRESIDENT

Charles J. Hitch

President of the University.

Chester O. McCorkle, Jr.

Vice President of the University.

Robert L. Johnson

Vice President—University Relations.

Angus E. Taylor

Vice President—Academic Affairs and Personnel.

John A. Perkins

Vice President—Administration.

James B. Kendrick, Jr.

Vice President—Agricultural Sciences and Director of the Agricultural Experiment Station.

Frank L. Kidner

Vice President—Educational Relations.

Durward Long

Vice President—Extended Academic and Public Service Programs.

Jay D. Michael

Vice President—Governmental Relations.

OFFICERS EMERITI

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

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

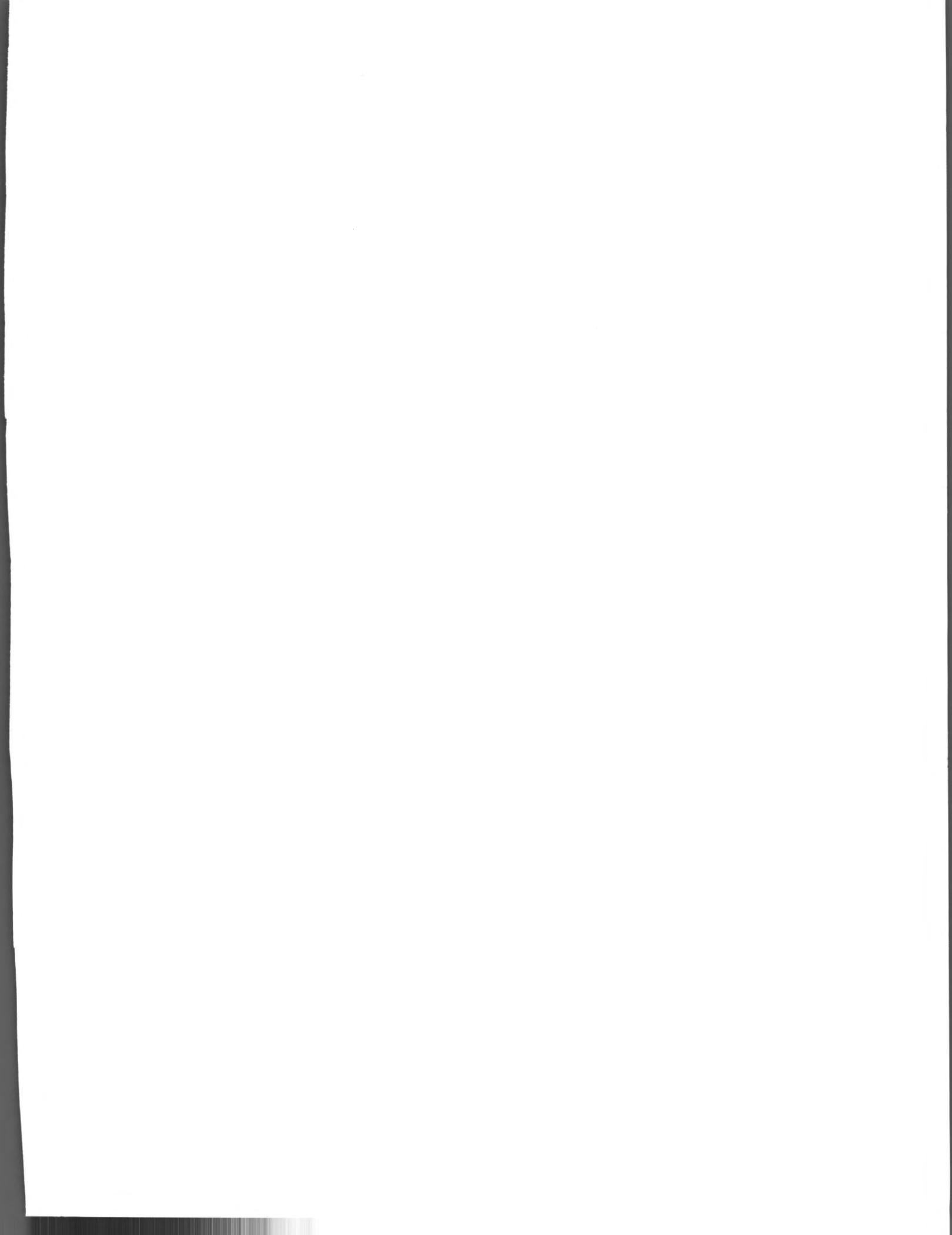
CHANCELLORS

Albert H. Bowker
Chancellor at Berkeley.

Appendix G

CURRENT FUNDS EXPENDITURES BY MAJOR UNITS AND FUNCTIONS BY FUND SOURCE 1973-1974

	Institutes			
	Scripps Institution of Oceanography	Geophysics and Planetary Physics	Marine Resources	Total
STATE OF CALIFORNIA				
General	\$ 3,536,838	\$148,928	\$223,501	\$ 3,909,267
Other	242,392	—	47,383	289,775
Total State of California	3,779,230	148,928	270,884	4,199,042
STUDENT TUITION & FEES	14,039	2,487	2,141	18,667
UNITED STATES OF AMERICA				
Grants—				
Department of Defense—Air Force	—	17,387	—	17,387
Department of Health, Education and Welfare	17,716	2,171	—	19,887
National Aeronautics and Space Administration	133,300	5,902	—	139,202
National Institutes of Health	194,034	—	—	194,034
National Science Foundation	5,738,205	414,583	262,533	6,415,321
Other	675,332	20,738	—	696,070
Total Grants	6,758,587	460,781	262,533	7,481,901
Contracts—				
Atomic Energy Commission	191,426	2,125	241,643	435,194
Department of Defense				
Air Force	353,552	—	—	353,552
Army	301,607	—	—	301,607
Navy	6,780,565	336,063	—	7,116,628
Department of Health, Education and Welfare	—	—	—	—0—
National Aeronautics and Space Administration	—	—	—	—0—
National Science Foundation	9,728,361	—	9,482	9,737,843
Other	210,661	—	1,521	212,182
Total Contracts	17,566,172	338,188	252,646	18,157,006
Total United States of America	24,324,759	798,969	515,179	25,638,907
ENDOWMENT FUNDS	406,911	21,429	3,832	432,172
GIFTS AND PRIVATE GRANTS	409,544	25,466	2,142	437,152
SALES AND SERVICES	57,097	(264)	8,781	65,614
ORGANIZED ACTIVITIES	4,839	—	—	4,839
OTHER SOURCES	42,721	455	60,909	104,085
AUXILIARY ENTERPRISES	—	—	—	—0—
RESERVES	—	—	—	—0—
Total Current Funds Expenditures	\$29,039,140	\$997,470	\$863,868	\$30,900,478



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