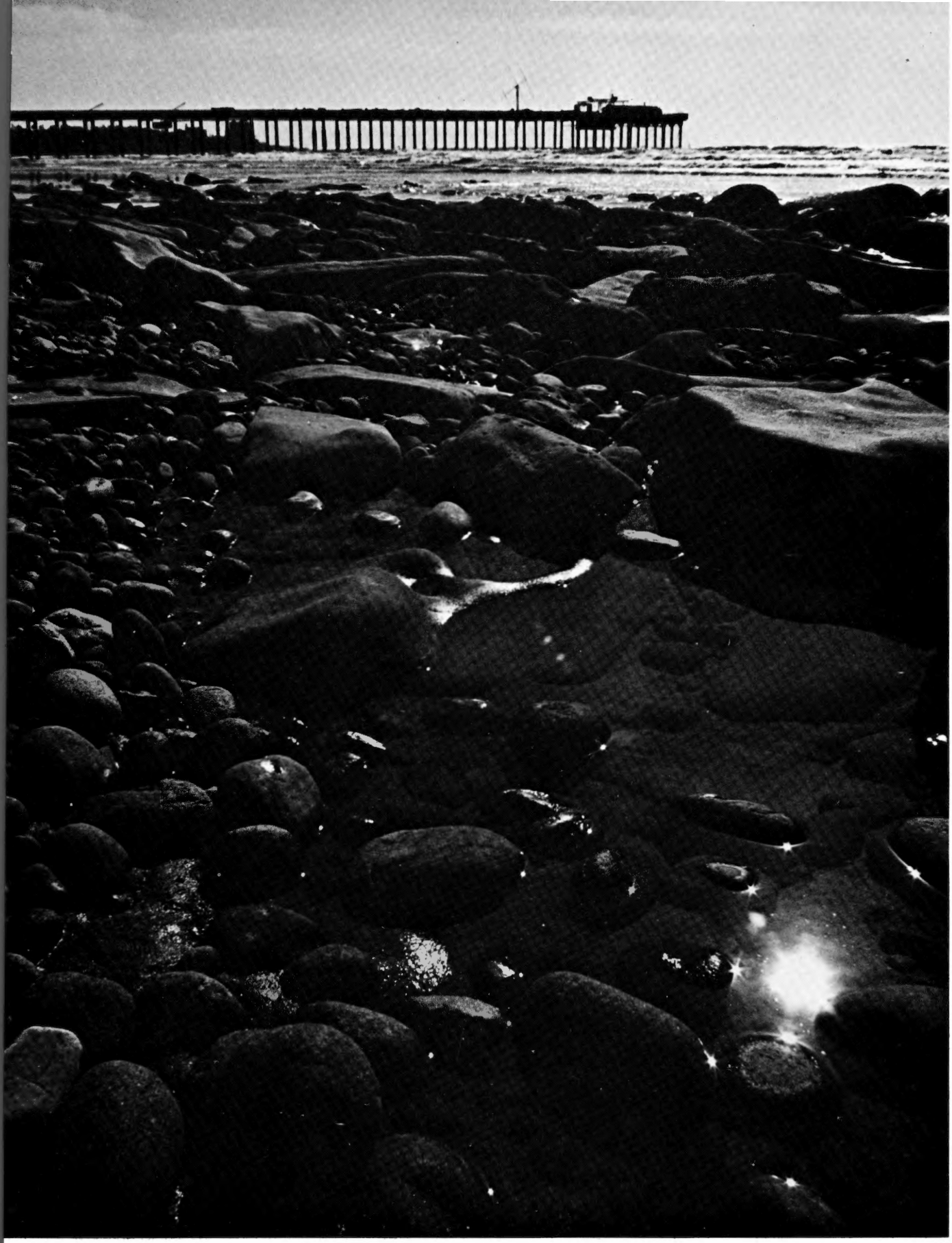
UNIVERSITY OF UCSD
CALIFORNIA, SAN DIEGO

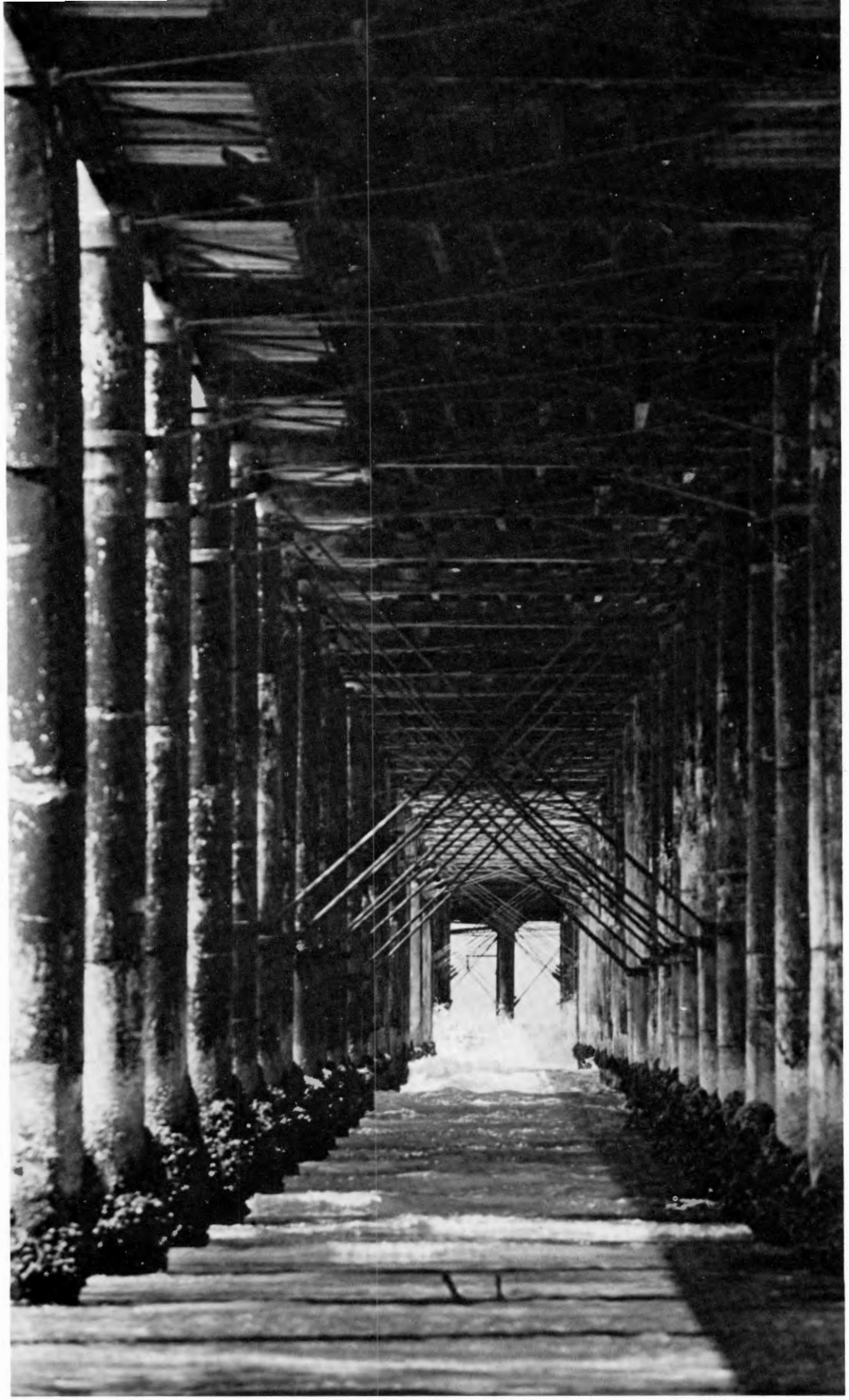
SIO 1971

. . . a report on the work and programs of
SCRIPPS INSTITUTION OF OCEANOGRAPHY
for the year ending June 30, 1971 . . .



. . . Then on the shore
of the wide world I stand alone, and think . . .

John Keats



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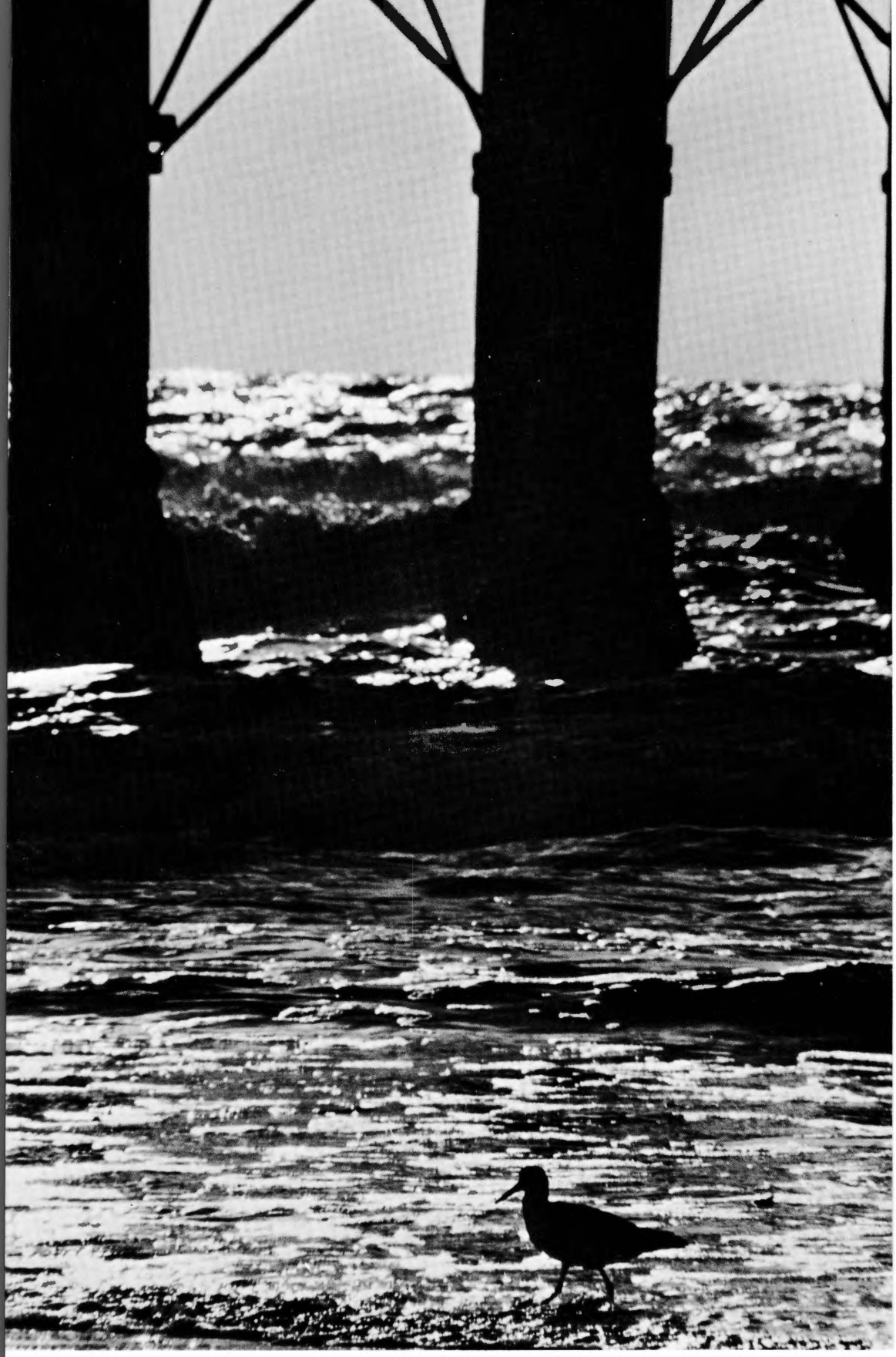

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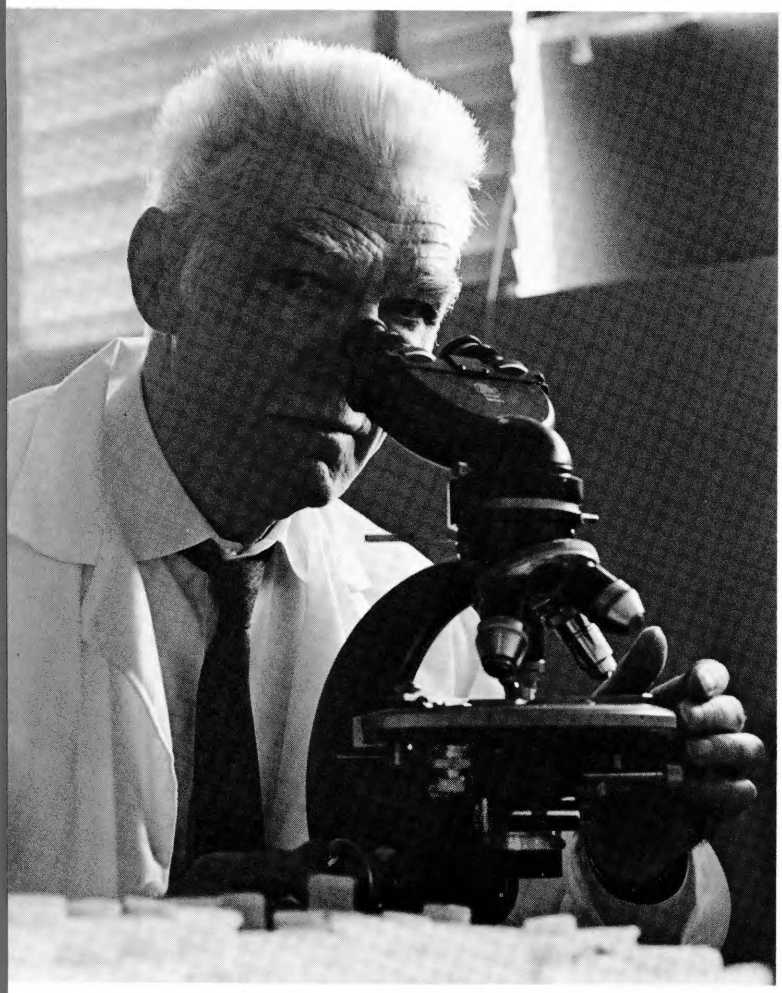
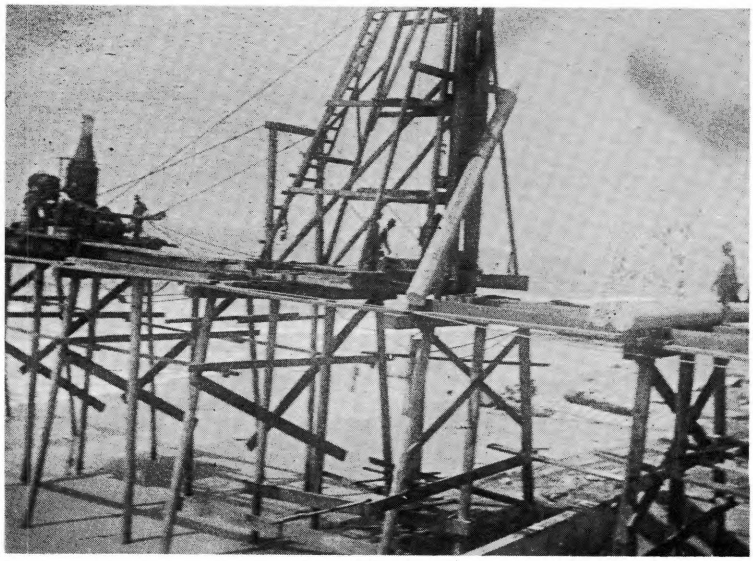


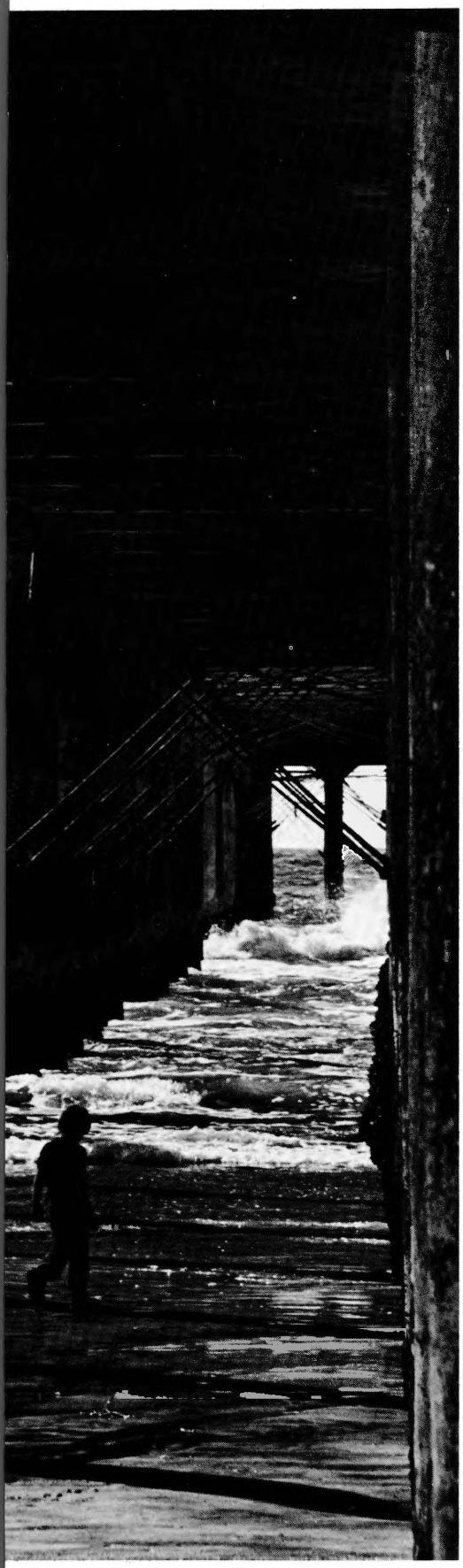
Dr. Milton N. Bramlette, professor emeritus of geology, was the first, in 1954, to demonstrate the value of calcareous nannofossils in determining the age of marine sediments. Such investigations have subsequently been initiated at many institutions and laboratories in the United States and Europe and have been of much importance in the study of ocean sediments taken during drilling operations of the Deep Sea Drilling Project.



About the cover:

Nearly the oldest and clearly the most prominent structure at Scripps is the pier. Reaching 1,000 feet to sea, it has formed a useful bridge between three major interfaces: land, sea, and air. Plans for the pier were approved in 1912 on the same day the Biological Station became part of the University of California. Built during 1914–15 at the then impressive cost of $36,000, its steel-reinforced concrete pilings were bored into the sea floor from a wooden tressel the timbers for which were floated as rafts from the mill to just outside the breakers at Scripps. Here the rafts were unlashed and the timbers washed ashore where man- and horse-power muscled them into position for tressel construction (see photographs). Daily sea temperature and salinity measurements have been made since mid-1916. Countless other measurements have been made as well—plankton, mussel growth, fouling and corrosion of industrial materials, and spindrift effect on paint. It also serves as primary input for saltwater to shore stations, a small boat storage and launch site, and a staging area for local work at sea. Yet in its leisurely youth, the pier afforded fishing space to local townsmen—25c a day or $20 a lifetime permit.

Shown on the cover is the well-worn chute at the seaward end of the pier through which 56-years' worth of instrument lowerings have been made to the sea 30 feet below. Estimates give another decade of life to the pier. When it passes, a whole era of oceanography will pass with it.



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This report is printed at no cost to the State of California.

INTRODUCTION

The year 1970–71 seemed to be no less turbulent for oceanographic affairs than those immediately preceding. However, it was a year of genuine loss to an important sector of oceanography that will take many years to overcome. The year 1970–71 marked the passing of three great men—Milner B. Schaefer, John Strickland, and Wib Chapman. Their individual and yet coordinated contributions to problems of the oceans' productivity formed the basis of almost the entire U.S. position in these affairs—nationally and internationally. Memorial statements have been and will be published elsewhere, but in this annual report we must note the great effort that will have to be made to fill the void.

Despite the violent fluctuations in funding support and massive governmental reorganizations, the Institution continued to grow and develop. The principal source of the external changes was and continues to be the shift in emphasis to the environment and the associated problems. Although Scripps as an institution is devoted to basic research in the oceans using the classical disciplines, the results of these researches usually supply the fundamental knowledge required to deal with environmental problems either directly or as spinoffs—and for global problems, not just the oceanic ones. Two of the best known examples are those of Dr. Tsaihwa J. Chow on lead and Dr. C. D. Keeling on CO_2. As a result, the demands on the Institution keep increasing to the extreme limit of personnel, space, administrative support, and available ship time.

Scripps area relative to main UCSD campus is shown in aerial view at right. Pier jutting to sea in lower left-hand corner of picture marks general site.

One of the unsung bits of Scripps public service is the hydrant near the pier; it provides seawater for home aquaria and lab experiments.

Former homes of Scripps staff members still dot the seaward slopes of the campus. Built circa 1915, these houses now serve as laboratories and offices.

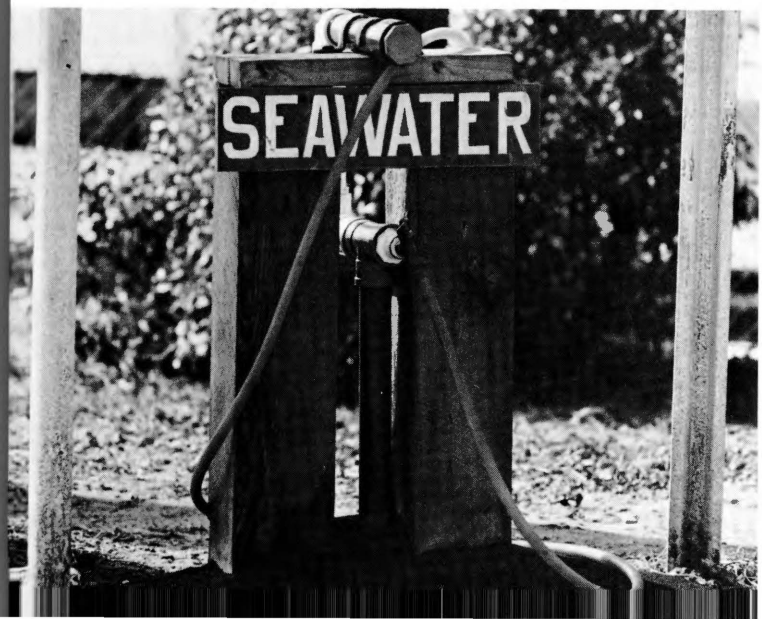
The other developing attitude on the part of government managers is the growing dependence on the "larger" programs. These are important programs that require major concentrations of manpower and money because of either synoptic or engineering considerations. The Deep Sea Drilling Project was the first in recent times. It is being followed by the Geochemical Ocean Sections Study (GEOSECS) and probably an important expansion in the North Pacific Buoy Program. These projects make extraordinary demands on the limited manpower of the oceanographic community, but they are very rewarding in their results and applications.

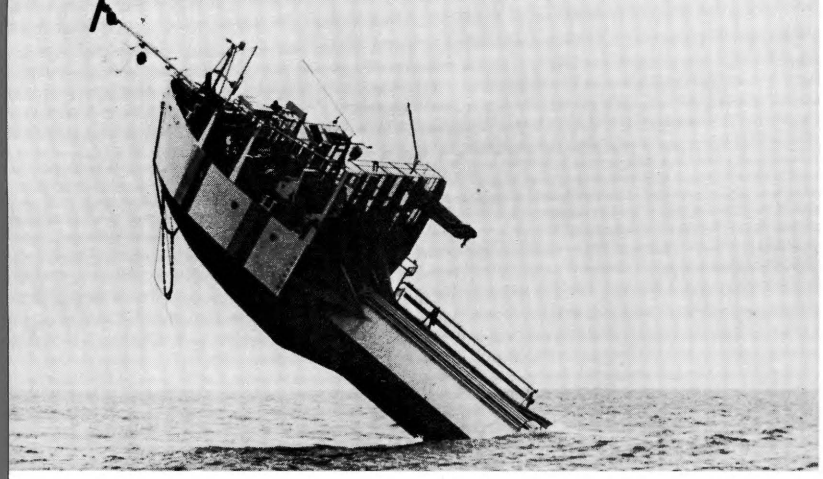
The principal governmental change is the formation of the National Oceanic and Atmospheric Administration (NOAA) within the Department of Commerce. This action is too recent, however, to have had as yet any major programmatic effects on SIO. The Office of Science and Technology in the Executive Office of the President has reinstituted the Interagency Council on Oceanography, and the Congress has passed and the President signed into law the creation of the National Advisory Committee on Oceans and Atmosphere. These two events have also been too recent to evaluate. I believe that all of this activity does presage a greatly increased involvement of the nation in oceanic affairs and even greater demands on the Institution.

Many of the major projects referred to earlier are being developed through the International Decade of Ocean Exploration program of the National Science Foundation. However, the decade will be more important than just representing coordinated scientific programs to develop the oceans' potential. In our estimate, it will represent a period of diplomatic activity with respect to the oceans second in importance only to the questions of disarmament. While most of the senior members of the Institution are involved individually in preparation for this activity, we have found it necessary to concentrate our activities in the Center for Marine Affairs. Just as we have had to depend on special interdisciplinary "mission-oriented" centers in the past for public service (such as the Marine Life Research Group to cope with productivity problems of the California Current system), so do we intend to use the Center for Marine affairs as a basis for studying an orderly political and economic development of the world's oceans.

William A. Nierenberg

William A. Nierenberg, Director
Scripps Institution of Oceanography





FLIP

R/V *ST-908*

SEAGOING OPERATIONS

Nimitz Marine Facility and Fleet

The research vessels that comprise the fleet of Scripps Institution during Fiscal Year 1971 included *Alexander Agassiz, Alpha Helix, George Melville, Ellen B. Scripps, Thomas Washington, Oconostota,* and *ST-908*.

During the year the fleet operated at sea a total of 1,514 days and traversed a total distance of 159,034 miles.

Major expeditions were carried out by *Alpha Helix, George Melville,* and *Thomas Washington.*

R/V *George Melville* began the fiscal year engaged in Leg II of Antipode Expedition, San Francisco to Adak, Alaska, under direction of Dr. George G. Shor, chief scientist. Work included seismic reflection profiling, deap-sea camera work and heat flow measurements. Subsequent legs of Antipode Expedition included Leg III in July and August, Adak to Osaka, Japan, for seismic reflection profiling, heat flow, camera, and dredge surveys, also under Dr. Shor; Leg IV in August and September, Osaka to Manila, Philippine Islands, for biological work, midwater trawling, and site surveying, under Dr. Richard H. Rosenblatt; Leg V, Manila to Port Louis, Mauritius, in September and October, for magnetometer, heat flow, and reflection surveying, under Paul J. Liebertz; Leg VI in October and November, from and returning to Port Louis, for magnetics, dredging, bottom topography, and surveying for Deep Sea Drilling Project (DSDP) sites, under Dr. Robert L. Fisher; Leg VII in November and December, 1970, from and returning to Port Louis, accomplishing work similar to that of Leg VI, again under Dr. Fisher; Leg VIII, January and February, 1971, Port Louis, to Mombasa, Kenya, for magnetics, dredging, bottom topography, and DSDP site surveys, also under Dr. Fisher; Leg IX in February and March, from and returning to Mombasa, for biological collecting and photography, under Prof. John D. Isaacs; Leg X, Mombasa to Colombo, Ceylon, March and April, for magnetics and seismic reflection profiling, under Dr. Shor; Leg XI, April and May, Colombo to Padang, Sumatra, for piston coring, dart coring, dredging, refraction, and magnetics, Dr. Joseph R. Curray; Leg XII, Padang to Singapore, Malaysia, May and June, for geophysical work and dredging, Dr. John G. Sclater. The ship, engaged in Antipode Expedition throughout the year, logged a total distance of 44,770 miles.

R/V *Thomas Washington* began the new fiscal year at Honolulu, having completed Leg VII of Seven-Tow Expedition. In July, Leg VIII from Honolulu to Adak, Alaska, involved study of benthic fauna under Dr. Robert R. Hessler. During Leg IX, late July to mid-August, a deep-tow survey was conducted in the Aleutian Trench by Dr. Fred N. Spiess enroute from Adak to Astoria, Oregon. Leg X in late August involved seismic reflection and dart coring under Dr. Eli A. Silver. Drs. Curray and Silver continued seismic reflection work and dart coring during September. The final leg of Seven-Tow Expedition was conducted between Eureka and the home port, San Diego, in late September. The work involved deep-tow surveys of several areas under direction of Dr. Spiess. During the last four legs of Seven-Tow Expedition, which took place during the fiscal year, *Thomas Washington* traveled 10,856 miles.

After an overhaul and upkeep period the ship departed San Diego on the first leg of Aries Expedition on November 14, 1970. Leg I, San Diego to Papeete, Tahiti, during November and December, under Dr. Edward Brinton, included zoography of the zonal band from 8° to 25° South Latitude. After spending Christmas Day at Papeete, the ship departed December 26 on Leg I-A, conducting biological work under Dr. Elizabeth L. Venrick, arriving at Wellington, New Zealand, on January 5, 1971. Leg II, under Joseph L. Reid, included current measurements and studies of water characteristics and topography along the rises between New Zealand and Australia. This leg was completed at Wellington on February 22. During Leg III, Wellington to Papeete, in March, work under Dr. John A. McGowan, chief scientist, included study of planktonic communities in the center of the large anticyclonic gyres of the Pacific.

Dr. Bruce A. Taft conducted studies of the Equatorial Undercurrent on Leg IV of Aries Expedition, Papeete to Honolulu, during April. On Leg V, Honolulu to Tokyo, during May and early June, dredging and magnetic surveys were conducted by Drs. Jerry L. Matthews and Bruce C. Heezen, the latter from Lamont-Doherty Geological Observatory. On Leg VI, Tokyo to Kobe to Yokohama, Japan, in June, Dr. Taft conducted measurements of the Kuroshio Current.

The end of the fiscal year found *Thomas Washington* at Yokohama. The ship was employed on Aries Expedition for 228 days during the year and logged 35,942 miles. During both Seven-Tow and Aries Expeditions combined, *Thomas Washington* operated 316 days and traveled 46,798 miles during the fiscal year.

R/V *Alpha Helix* was utilized for a series of programs conducted off the coasts of California, Oregon, and Washington during July and into late August, 1970. In July the work included phytoplankton studies by Dr. Richard W. Eppley and midwater trawls by Dr. James J. Childress, of UC-Santa Barbara. Marine ecological studies by Drs. Mario M. Pamatmat, Bruce W. Frost, and George W. Anderson of the University of Washington took place in late July. Dr. Pamatmat took STD measurements, core samples, and bottle casts in August.

Alpha Helix departed San Diego on August 27 on the Antarctic Expedition. A number of programs were conducted enroute to Palmer Station in the Antarctic. These included sea snake investigations under Dr. William A. Dunson, Pennsylvania State University, San Diego to Balboa, Canal Zone, August and early September; biological reef studies under Dr. William A. Newman in Panamanian waters, September and October; physiological research under Dr. Peter W. Hochachka, University of British Columbia, October and November, Balboa, Canal Zone to Callao, Peru. The ship then proceeded from Callao to Punta Arenas, Chile, arriving December 19. Dr. Harold T. Hammel and party joined the ship on December 29 and *Alpha Helix* departed that date.

The ship arrived at Palmer Station on January 2, 1971. The facilities in the ship together with those of a shore station were utilized for physiological research until late February, 1971. Investigators included Drs. Edvard A. Hemmingsen, Fred N. White, Gerald L. Kooyman, Joseph P. Schroeder, Harold T. Hammel, Robert E. Johannes, Ronald W. Millard, Larry I. Crawshaw, David E. Murrish, and Per F. Scholander, as well as graduate students William Milsom, Kenneth Morgareidge, and James E. Smith.

R/V *Ellen B. Scripps*

R/V *Thomas Washington*

Alpha Helix returned to Punta Arenas, February 27. After replenishment of supplies, the ship proceeded first to Valparaiso, Chile, then to Papeete, Tahiti, and then on to Kwajalein, Marshall Islands, arriving on April 21. The ship proceeded to and took station at Eniwetok, Marshall Islands, on April 26. Dr. Robert E. Johannes, University of Georgia, Athens, and partly conducted a comprehensive study of coral reef metabolism in the vicinity of Eniwetok Atoll. The ship departed for Honolulu on June 20. During Fiscal Year 1971, the ship spent 357 days at sea or on station and logged 28,790 miles.

R/V *Alexander Agassiz* was employed during the fiscal year primarily in the Marine Life Research Group program off the coast of California and Baja California. MLRG work involved 119 days at sea. Other work during the year included these operations: Institute of Marine Resources, 20 days; Institute of Geophysics and Planetary Physics, 8 days; Oceanic Research Division, 5 days; Marine Biology Research Division, 28 days; Geological Research Division, 2 days; student cruises, 27 days. The ship operated at sea 209 days and logged 15,669 miles during the year.

R/V *Ellen B. Scripps* carried out operations of short duration in California and Mexican coastal waters. The versatility of the vessel was demonstrated frequently through rapid changes of equipment in minimum turn-around time. Work at sea by various departments included: Oceanic Research Division, 27 days; National Marine Fisheries Service, 5 days; Marine Biology Research Division, 3 days; Visibility Laboratory, 23 days; Marine Physical Laboratory, 12 days; Institute of Geophysics and Planetary Physics, 49 days; other, 51 days. The *Ellen B. Scripps* operated a total of 170 days and traveled 17,400 miles during the fiscal year.

R/V *Oconostota* operations were limited during the year. The ship was not assigned a permanent crew for several months, but was operated on occasion with available seagoing personnel supplemented by Marine Facilities' shop personnel. The ship was employed principally by the Marine Physical Laboratory. Work included towing of FLIP, deep-tow operations and use of transponders for a combined total of 37 days. The ship was also used by graduate student Theodore C. Tutschulte for 15 days in an ecology program. The ship logged a total of 3,196 miles and operated 52 days.

R/V *ST-908* carried out small craft work for a total of 45 operating days. The boat was used regularly by graduate student Gary Smith in ecological studies with gravity core sampling in the Huntington Beach area. She logged 2,411 miles during the year.

Major Expeditions

As indicated from the detailed account of fleet operations above, research vessels serving the Institution were busy during the year in southern California and Baja California waters and in regions thousands of miles from home port. Three major expeditions—Antipode, Antarctic, and Aries—got under way during the year and Seven-Tow Expedition was concluded. Its research is outlined below.

Seven-Tow Expedition. Additional evidence of the movement of the earth's crust beneath the ocean was reported by Scripps Institution scientists when R/V *Thomas Washington* docked in San Diego September 25, 1970, to conclude Seven-Tow, a 35,000-mile, eight-month, multi-discipline research expedition into the Pacific.

Magnetic surveys of many of the extinct undersea volcanoes along a long chain of seamounts between Samoa and Honolulu and extending from Christmas Island, near the Equator, to Johnson Island, 1,000 miles farther northwest, showed that at the time of their eruption they were located as much as 1,500 miles south on the other side of the Equator.

"Large-scale northward shifts of the earth's crust beneath the center of the Pacific have since carried the seamounts pickaback to their present locations," Dr. Edward L. Winterer, who headed one leg of the expedition, reported.

"Fossils dredged from the tops and sides of the seamounts enabled us to fix the age of the volcanoes. The fossils are the remains of microscopic animals that floated in the near-surface waters. Their shells settled onto the tops of the extinct volcanoes. Some of the fossils are of Late Cretaceous age and indicate that the seamount where we found them is at least 75 million years old."

Discovery of a series of mysterious scars on the ocean floor off Monterey also was reported by Dr. Fred N. Spiess, who was scientist-in-charge on the last leg of Seven-Tow.

Dr. Spiess said the scars were in the outer part of the gently sloping Monterey Fan, in water nearly three miles deep. He said there were at least six of the cracks, up to 50 feet wide and a mile long.

"We saw these features with the deep-tow side-looking sonar which we were using to map the sea floor," he said. "All of us were perplexed as to their origin."

In another region of the Pacific, one team of investigators found evidence indicating an eastward movement of the Tonga Island away from the Fiji and Lau Islands.

"We discovered an ocean ridge crest formed by the upward intrusion of basaltic-type rocks in an area of high earthquake activity and heat flow," Drs. John G. Sclater and James W. Hawkins reported.

"The likelihood of such an intrusion had been suggested to us by our earlier investigations on Scripp's Nova Expedition."

Dr. Sclater said it has been suggested by a Scripps graduate, Dr. Daniel Karig, now at UC-Santa Barbara, that this type of intrusion may be responsible for the formation of much of the ocean floor lying to the west of the island arcs in the western Pacific.

"In any event, the mechanism forming the ridge crest in the Lau Basin has been responsible for the gradual spreading apart of the Fijis and the Laus eastward and westward," he added.

Another phenomenon discovered by Dr. Sclater and his associates was a strong evidence for a core of water at some 15,000 feet in the Tonga Trench south of the Samoa Island that is much colder than surrounding waters.

It is thought that this water core is the western deep boundary current that transports cold, Antarctic bottom water from south of New Zealand into the North Pacific.

In a resuming study of the Horizon Guyot, discovered during the Mid-Pac Expedition of 1950 and named for the former Scripps vessel *Horizon*, Dr. William R. Normark and his colleagues used stereophotography and other deep-towed instrument

R/V *Melville*

R/V *Alexander Agassiz*

techniques to study the sea floor on the crest of the guyot. Graduate student Peter Lonsdale, who was aboard, said studies of cores and other ocean-bottom samples provided a history of the sediments and the origin of the ridge of which the Horizon Guyot is a part.

This guyot had been drilled in an earlier Deep Sea Drilling Project operation, but the work was stopped when flint-like layers of chert were struck. Elsewhere, the water currents swirling around the guyot had swept the surrounding sand away, undercutting the chert layers and leading to their collapse. The formation of bottom sand ripples and measurements taken by current meters indicated a north-south movement of the water at some 16 centimeters per second.

Working on an abyssal plain in 15,000 to 18,000 feet of ocean between Hawaii and the Central Aleutians, Dr. Robert R. Hessler and his associates probed the bottom fauna of the biologically sterile central core of the North Pacific.

"Because of the low nutrient levels of the surface waters in this central core, there is very little biological productivity," Dr. Hessler said.

"Whatever organic material is produced in the upper layers is mostly used up before it can find its way to the sea floor, hence there is a minimum amount of animal life at the bottom.

"We were interested in what the animal community is like at those depths. By taking box core samples and epibenthic sled samples of the sea floor, we found a wide variety of macro invertebrates, such as very small crustaceans, bivalves, clams, and worms."

He said that animal life in the sea varies with the environment, as does animal life on land, and added that the sterility and depth of the water in the area investigated made for different species, genera, and families than were to be found in sea life at higher water levels in the ocean.

Seven-Tow Expedition was funded mainly from contracts and grants provided by the Office of Naval Research and the National Science Foundation (NSF).

The expedition was named Seven-Tow because a portion of the research utilized Scripp's Marine Physical Laboratory (MPL)-developed deep-tow device, an electronic instrument towed by the vessel for precise mapping of the ocean floor and geological formations along deep-sea trenches. The instrument had been used on earlier expeditions by MPL.

Other work of the expedition included radio-carbon sampling of seawater, collection of atmospheric dust, analyses of noble gases in seawater, and site selection work off the coast of Washington for Deep Sea Drilling Project operations which Scripps manages for NSF.

Dr. John D. Mudie was coordinator for the voyage.

Scientists-in-charge of various legs of the voyage, besides Drs. Mudie, Winterer, Hessler, Normark, Sclater, and Spiess, included Drs. Joseph R. Curray, Robert L. Fisher, and Eli A. Silver, and Stuart M. Smith. Twenty Scripps graduate students participated in the expedition.

Duties of the ship's master were handled by Capts. Terry Hansen and Alan W. Phinney. Two crew rotations were necessary because of the length of the expedition.

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. Additional programs will be made available as the need arises. 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 is chaired by Dr. Edward L. Winterer, professor of geology. Dr. Richard H. Rosenblatt, associate professor of marine biology, is vice-chairman.

R/V *Alpha Helix*

R/V *Oconostota*

Activity on the fantail of R/V Thomas Washington *during Seven-Tow Expedition, a 35,000-mile, eight-month, multi-discipline research cruise into the Pacific Ocean.* —Phil Rapp

GRADUATE CURRICULAR PROGRAM. A brief description of the seven curricular programs, whose 57 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.

Present research activities within the curricular group include studies of deep circulation and deep fish population; deep-sea autonomous vehicles, instruments, basic control devices and special collecting gear; seismic surveys of the mantle; ocean bottom microseisms and crustal displacements associated with earthquakes; surveys of bathymetric-magnetic trends; design and construction of special-purpose ocean vehicles (ships, submarines, platforms) such as FLIP; remotely operated cable-connected vehicles and stations on the sea floor; sonar systems and sonar signal processing equipment; underwater communication and signal detection; underwater photography and television; visibility by swimmers; underwater lasers; remote sensing of sea-surface temperature, roughness, and marine resources from aircraft and orbital spacecraft; meteorology above the oceans; turbulent flows and formation of barrier beaches; and mechanisms of currents, sand transport, and sediment transport in the surf zone, the shelf, and in submarine canyons.

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. J. Freeman Gilbert). 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. It is anticipated that the geophysical curriculum and the physical oceanography curriculum will emphasize many points in common.

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 the introductory course of the curriculum, "Marine Life." 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. Charles D. Keeling). 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 the sedimentary solid phases, and with plants and animals form the basis 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. Joseph R. Curray). 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 sub-program 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. Research areas include tectonics and volcanism; geomorphology, structure, and deformation of the oceanic crust and continental margins, utilizing both geophysical and geological techniques; deep-sea and continental margin sedimentation, stratigraphy, and paleontology; and beach and nearshore processes. 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 islands, 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; circulation and mixing of oceanic water masses based on carbon, oxygen, carbon-14, radium, radon, stable isotopes, and rare gases; 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.

Betty Jean Sackville (left) and Susan Jorgensen work in Graduate Department office. Enrollment at the start of 1970 school year totaled 168 graduate students.

Physical Oceanography (Dr. Charles S. Cox). 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 1970, 38 new students began their graduate studies. Of these, 6 were in marine biology, 5 in geophysics, 5 in biological oceanography, 4 in physical oceanography, 3 in marine chemistry, 9 in applied ocean sciences, and 6 in geological sciences. Fifteen were California residents, 15 were from out-of-state, and 8 were from foreign countries. Enrollment at the start of the 1970 school year totaled 168 students.

During the Academic Year 1970–71, 13 Master of Science degrees and 21 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.

The following abstracts of dissertations by Clement G. Chase, Jeffrey B. Graham, James J. McCarthy, Robert J. Tait, and Ray F. Weiss are indicative of the varied subjects chosen by candidates for the doctoral degree.

Dr. Chase's dissertation is entitled "Tectonic History of the Fiji Plateau." He is now an assistant professor of geology at the University of Minnesota, Minneapolis. The abstract of his dissertation follows:

> The Fiji Plateau is a high, hot area of young oceanic crust. It is bounded on the north by a Cretaceous Pacific archipelago, and to the east and west by the Tonga and New Hebrides island arcs which go back to the Eocene. The Fiji Islands are an Eocene and younger continental mass formed within the ocean basin. Plate tectonics provides the key for understanding the area. Marine geological and geophysical data from S.I.O. expeditions, especially Nova, and published seismic, gravity, and island geologic information provide the basis for the interpretation.
>
> Fiji is now flanked by three active sea-floor spreading centers which are part of a very complicated transform linking the Tonga and New Hebrides crustal consumption zones. Extension in the Lau Basin is also involved. Magnetic anomalies and seismicity permit six small blocks and the large Pacific and Australian plates to be distinguished, and some idea of their relative motions to be gained.
>
> From published magnetic anomaly and fracture zone data, a detailed history of the Tertiary motions of the Pacific and Australian plates with respect to Antarctica has been deduced. By a suitable choice of plate boundaries, horizontal movements of the larger tectonic units of the Fiji Plateau region can be worked out for the entire Tertiary. This reconstruction successfully accounts for many hitherto unexplained bathymetric and geologic features of the area. The history proposed for the Fiji Plateau is probably unique among the world's oceans.

Dr. Graham is now associated with the Smithsonian Tropical Research Institute in Balboa, Canal Zone. The title of his dissertation is "Aspects of Temperature Sensitivity in Some Tropical Inshore Marine Fishes." The abstract of his dissertation follows:

> A study of the temperature physiology of neotropical fish species has been conducted. A flow-through respirometer was used to determine routine oxygen consumption rates at different temperatures. Upper and lower temperature tolerances were also determined.
>
> In a comparative study of closely related Atlantic and Pacific species pairs, it was found that in general, the oxygen consumption rate of Atlantic species is reduced more at low temperatures than that of Pacific species. Also, Pacific species are more tolerant of lower temperatures but less tolerant of higher temperatures than Atlantic fishes. The magnitudes of the sensitivity differences vary with different species pairs. In the case of Atlantic and Pacific species of the genus *Bathygobius,* sensitivity differences are small and can be removed by acclimating both species to the same temperature. The differences between Atlantic and Pacific species of *Apogon* are larger, and still exist after acclimation.
>
> The adaptation of Pacific fishes for the low temperatures of the dry season was studied. No seasonal temperature compensation (acclimatization), such as that commonly found in temperate fishes, is evident in the species studied, but they are capable of acclimating to low temperatures in the laboratory.
>
> A positive correlation between upper lethal temperature and habitat temperature of *Abudefduf troschelii* from different locations in the eastern tropical Pacific, the wide thermal tolerances found for the species in this study, and their capacity for cold acclimation attest to the eurythermality of tropical marine fishes.

Dr. McCarthy is now a postdoctoral fellow in the Department of Earth and Planetary Sciences at Johns Hopkins University, Baltimore, Maryland. The title of his dissertation is "The Role of the Urea in Marine Phytoplankton Ecology." The abstract of his dissertation follows:

> The distribution of urea in seawater, the production of urea by marine fish and zooplankton, and the utilization of urea by marine phytoplankton were studied.
>
> Urea analyses of samples from the Central Pacific and the coastal waters off La Jolla increased by better than 200% the total number previously reported. The values for all studies have been low (usually < 1.0 μg-at N/1). In the Central Pacific urea concentrations showed a high degree of variability on a vertical scale of a few meters. The results of a 2½ month semi-weekly sampling program off the coast of La Jolla showed that the median concentrations of nitrate, ammonium, or urea were not different at 2 stations 1.5 km apart but the shape of the urea profiles for any one day were generally less similar than those of ammonium and considerably less than those of nitrate. A period of higher seawater urea concentrations was associated with a heavy infestation of blue sharks.
>
> Urea excretion was studied for ecologically important species of fish and zooplankton. Urea accounts for approximately 20% of the ammonium + urea nitrogen released by *Engraulis ringens, E. mordax,* and *Trachurus symmetricus* and approximately 30% of that released by recently fed *Calanus helgolandicus* and a mixture of *C. chilensis* and *Clausocalanus* spp. Starvation in the fish experiments increased the percentage of nitrogen released as urea and in the zooplankton experiments urea release ceased approximately as long after feeding as would be necessary to void the gut.
>
> Forty clones representing as many as 35 species of phytoplankton were tested for capacity to utilize urea as a sole source of nitrogen. Over half of the isolates showed at least

fair growth on urea and this capacity varied between genera, within genera, and between clones within a species. Various experiments indicated that the bacteria common to laboratory phytoplankton cultures neither utilize nor hydrolize urea.

Half saturation constants (K_s) for neritic diatoms capable of utilizing urea were determined from short-term uptake studies with ^{15}N labeled urea. The results were similar to those determined earlier for ammonium. This indicates that these species are capable of utilizing ecologically significant concentrations of urea. Two of 3 species unable to grow on urea showed reasonable patterns of short-term uptake which implied that the assimilatory rather than the uptake processes were defective with regard to urea utilization. The third species initially took urea into the cells but then released it back into the medium.

Phytoplankton were collected and grown in large cultures at sea to determine the effects of nitrate, ammonium, and urea as nitrogen sources. The depletion of nitrogenous nutrients was monitored and uptake rates were estimated using ^{15}N labeled nitrate, ammonium, and urea. The presence of nitrate had little if any effect on ammonium uptake and suppressed urea uptake to approximately 40%. The presence of ammonium effectively prevented the uptake of either nitrate or urea. The presence of urea had little if any effect on ammonium uptake and suppressed nitrate uptake to approximately 40%. Phytoplankton growth rates estimated from ^{15}N uptake agreed rather well with measured increases in particulate nitrogen and cell numbers and decreases in nitrogenous nutrients.

The uptake of nitrate, ammonium, and urea by natural phytoplankton populations was studied at 9 stations off the coast of southern California. The average C:N uptake ratio was 12.4. The percentage of the total phytoplankton nitrogen productivity accounted for by urea varied from $< 1\%$ to $> 60\%$ and for the entire study averaged 28%. The percentage of available nitrogenous nutrient (nitrate + ammonium + urea) utilized per day varied among the stations with a minimum of 5% at Station 4 (12 km off San Diego) and a maximum of 46% at Station 19 (off White Point.)

Dr Tait is now an assistant professor of oceanography at the University of Hawaii, Honolulu. The title of his dissertation is "Edge Wave Modes and Rip Current Spacing." The abstract of his dissertation follows:

On straight beaches where the depth contours are parallel to the beach, nearshore circulation patterns are commonly determined by interactions between the incident waves and edge waves.

Incident waves under such conditions have, in the past, been shown to generate edge waves of their own frequency with a number of possible wavelengths. The parameters which determine these wavelengths (L_e) are the beach slope in radians, β, and the radial frequency of the incident waves, σ_i. They are known to be related by

$$L_e = \frac{2\pi g}{\sigma_i^2} \sin (2n + 1)\beta$$

where g is the acceleration of gravity and n is the modal number which can be zero or any positive integer such that

$$(2N + 1)\beta \leq \frac{\pi}{2}$$

Observations by previous workers have shown that usually one of these possible edge wave modes will dominate giving a periodic variation in breaker height along the beach whose repetition interval is one wavelength of the edge wave. Rip currents are known to occur at locations of lowest breaker height in this pattern. Thus, in order to predict rip current spacing it is necessary to predict the wavelength of the dominant edge wave mode.

To develop a predictive model, the edge wave theory developed by Ursell in 1952 was extended to show the behavior of the sea surface and the velocity field due to edge waves. Since edge wave theory was only valid in regions satisfying the assumptions of potential theory, the breaking of incident waves provided the location of an additional boundary condition. Any edge wave mode which had its on-offshore velocity, u, go to zero at the break point would best satisfy this new boundary condition.

Laboratory tests of this model were conducted by eliminating all but one possible mode at a time, for a given beach angle and incident wave frequency, and then measuring its equilibrium amplitude at the break point of the incident waves. The mode which had the highest amplitude for a particular set of conditions was considered to be the most efficiently coupled to the incident wave and therefore most likely to occur in nature. These tests verified the model for plane beaches with slopes between 0.070 and 0.100 radians and suggested that maximum edge wave amplitudes could be expected to be less than one-sixth to one-quarter of the incident breaker amplitude.

Synoptic measurements of rip current spacing and digital wave data on two natural beaches extended the applicability of the model to real beaches with slopes of 0.025 to 0.055 radians and 0.110 to 0.150 radians.

At beach slopes greater than 0.090 radians certain ranges of breaker locations were not covered adequately by the theoretical model. Results from both the field and laboratory measurements indicated that in these ranges an edge wave of somewhat lower order resonance known as the "cut-off" mode often combined with the longest regular edge wave mode to dominate. The cut-off mode wavelength is $\frac{2\pi g}{\sigma^2}$ which could be very close to the longest regular edge wave mode, accounting for their combining into a higher order resonance than either would achieve alone.

Thus, the resultant predictive model is based on three premises: (1) an edge wave mode whose on-offshore velocity is near zero at the break point will have a high probability of occurrence; (2) the main exception to (1) is that the second highest numbered mode rarely occurs; and, (3) on steeper beaches ($\tan\beta > 0.1$) a region exists where (1) cannot be applied, and here the longest edge wave mode commonly appears. Using this approach, errors in predicted rip current spacing are commonly less than $\pm$ 20%.

Dr. Weiss is now a postgraduate research geologist in the Geological Research Division at Scripps. The title of his dissertation is "Dissolved Gases and Total Inorganic Carbon in Seawater: Distribution, Solubilities, and Shipboard Gas Chromatography." The abstract of his dissertation follows:

This dissertation is concerned with the study of dissolved gases and total inorganic carbon in the sea. Concentrations of dissolved helium, neon, argon, and in most cases nitrogen, are conservative quantities in the sea, and thus are potentially important tracers of oceanic circulation and mixing processes.

The isotopes helium-3 and helium-4 are additionally of great geophysical interest because of indications that "excess" amounts of these gases are injected into the deep ocean from the interior of the earth. The accurate knowledge of the solubilities of these gases is essential for the understanding of their distributions in the sea. Accordingly, the first part of this dissertation was directed to the solubility problem. Existing data on nitrogen, oxygen, and argon solubilities in seawater were fitted to thermodynamically derived equations using the Setchénow salting-out relation. New solubility measurements were made to confirm the use of the Setchénow relation for argon in seawater. Then the solubilities of helium and neon in water and seawater were measured and fitted to the same system of equations. The fractionation between helium-3 and helium-4 in solution was also measured as part of this work.

Because of their high diffusivities and low concentrations in seawater, sampling requirements for helium and neon are exceptionally stringent. A "Piggyback" sampler for collection of gas-tight sealed water samples was developed. Tests of the flushing characteristics of normal oceanographic sampling bottles were also made.

Dissolved oxygen and total inorganic carbon together make up the most important chemical system in the sea. The carbon dioxide cycle in nature is closely tied to this oceanic system. In particular, variations of carbon-14 in the deep-sea are strongly influenced by the rate of carbon dioxide production by oxidation and dissolution processes. The rate of oxygen consumption in the deep ocean is at present very poorly known. Acurate measurement of the relationship between total inorganic carbon and oxygen, especially in the deep water where advection is slow and non-conservative processes can be evaluated, is prerequisite to understanding the entire system. Therefore, a seagoing gas chromatrographic method for the rapid and precise determination of dissolved nitrogen, oxygen, argon, and total inorganic carbon in seawater was developed. Extensive intercomparisons with other analytical techniques were made, and the method has been used successfully at sea.

An example of the use of nitrogen, argon, and total inorganic carbon measurements for a specific problem is given for the Red Sea Brines. The data were used to show that the brines can only have been formed from warm surface waters which today are present only at the extreme southern end of the Red Sea, far from the location of the brines.

The availability of the new solubility data has also made possible the interpretation of saturation anomalies for helium, neon, and argon in the oceans. The results of this work show that much of the "excess" helium in the oceans which had been attributed to radiogenic sources, is in fact due to kinetic processes involving the entrapment of air at the sea-surface.

RESEARCH ACTIVITIES

Among research highlights for the period covered by this report were the establishment of the Center for Marine Affairs, the initiation of operational plans for GEOSECS (Geochemical Ocean Sections Study), and the continued successful operation of the Deep Sea Drilling Project.

Center for Marine Affairs

The action of some nations in extending their territorial claims as far as 200 miles out to sea—an action that raises an issue disturbing many scientists, that of freedom to perform research—became the central topic of an interdisciplinary study to be undertaken by a group of young social scientists who will be the first visiting fellows at Scripps's new Center for Marine Affairs.

The Center was established in July, 1970, with funds from a Ford Foundation grant. Director of the Center is Dr. Warren S. Wooster, professor of oceanography and president of the Scientific Committee on Oceanic Research (SCOR), a scientific advisory body to the oceanographic program of UNESCO.

The objective of the Center is to involve specialists from the social sciences, government, and other fields outside of the natural sciences in consideration of the scientific aspect of marine affairs. Brought together in the Center, both scientists and policy makers should gain insight into the extent and nature of the interaction between marine science and man's activities in and concerning the ocean.

The program functions at the postdoctoral level, and the visitors participate in team studies of important problems in marine affairs for periods of six months to a year.

The first problem to be tackled, in a nine-month study to begin in September, 1971, is that of determining the conditions necessary for freedom of scientific research in the ocean. Restrictions on the type of ocean research permitted are increasing, and coastal states are claiming jurisdiction over more and more ocean territory; the study will try to interpret these restrictions and to understand their effect on the acquisition of scientific knowledge and on use of the ocean and its resources. The developing countries are notably apprehensive about scientific research off their shores, and the study will pay particular attention to their needs that could be met from the ocean and the extent to which meeting these needs depends on ocean research.

The study team will consist of two political scientists, a lawyer, and a natural resource specialist. They will be joined during part of the study by a science attaché from the French Embassy and a lawyer from the Department of Defense. In the spring of 1972, a workshop is planned in which the findings of the team can be discussed with a variety of interested natural and social scientists. The eventual report will present options for use in discussions of the Law of the Sea Conference planned for 1973.

A second study, to begin in early 1972, will deal with marine science and international pollution policy, and, more specifically, with the continuing dynamic interactions between scientific considerations and the development and conduct of international marine pollution policy. How are the results of scientific investigations to be made available to policy makers, and how is their use of these results to be reviewed and evaluated? The question has obvious applications that go far beyond marine science.

Deep Sea Drilling Project

The Deep Sea Drilling Project (DSDP) is into the third year of drilling and coring the deep ocean basins in water depths exceding 20,000 feet and with penetrations up to 3,900 feet below the sea floor.

DSDP is funded by the National Science Foundation through NSF's National Ocean Sediment Coring Program. Scripps, in turn, subcontracts to Global Marine Inc., for use of the drilling vessel *Glomar Challenger*. Global Marine provides the drilling crew and the ship's crew. Scientific advice and guidance is provided through the panel system of the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES). Member institutions of JOIDES are Lamont-Doherty Geological Observatory, Columbia University, Palisades, New York; the Rosenstiel Insti-

Deep Sea Drilling Project ship Glomar Challenger *drills in open ocean. Computer-controlled dynamic positioning system keeps her over core hole.*

tute of Marine and Atmospheric Sciences, University of Florida, Miami; the University of Washington, Seattle; Woods Hole Oceanographic Institution, Woods Hole, Massachusetts; and Scripps.

Dr. William A. Nierenberg, director of Scripps, and Dr. Melvin N. A. Peterson are the co-principal investigators for the project. Dr. N. Terence Edgar is the chief scientist of the project and Valdemar F. Larson is the head of operations and engineering. Oscar E. Weser is the senior staff scientist. Other staff scientists are Dr. Peter R. Supko, Dr. Anthony C. Pimm, Dr. Ansis G. Kaneps, Dr. Peter H. Roth, Robert E. Boyce, Dr. Thomas A. Davies, Paula J. Worstell, Lillian F. Musich, and E. Dean Milow.

Cores that are taken from the Atlantic Ocean are kept in the repository at the Lamont-Doherty Geological Observatory, and those recovered from the Pacific are stored at Scripps. William R. Riedel of Scripps is the curator of DSDP cores. Sediment samples from these repositories are distributed to scientists throughout the world.

The initial scientific results and descriptions of the cores are published in a series of volumes entitled "Initial Reports of the Deep Sea Drilling Project." These are authored by the participating scientist of each operating leg of the project. Dr. Supko of Scripps coordinates the publication and editing of these reports, which will provide the basis for selection of core samples. They are available for purchase through the United States Government Printing Office, and they will also be placed in many public and private libraries throughout the world.

A. R. McLerran, field project officer for the National Science Foundation, has his office at Scripps to provide liaison between DSDP and the Foundation.

In the initial 18 months of drilling, the D/V *Glomar Challenger* traversed both the Atlantic and Pacific Oceans. During the 30-month extension provided by the National Science Foundation, the geographic coverage was expanded to include the Indian Ocean and higher latitudes in the Atlantic and Pacific. During Fiscal Year 1971, the vessel made six cruises, each of approximately two months' duration, extending from the Mediterranean Sea through the equatorial Atlantic, Caribbean, eastern central Pacific basins, and the Northeast Pacific, with emphasis along the continental margin of northwestern North America.

Scripps scientists who participated in these cruises of the *Glomar Challenger* included Drs. Pimm, Supko, and Roth on the cruise from Lisbon to San Juan; Drs. Edgar and Joris M. Gieskes, and Boyce and Riedel from San Juan to Panama; Dr. Kaneps from Panama to Hawaii, Dr. Edward L. Winterer, Richard O. Jarrard, and Dr. Roth from Hawaii to Hawaii; Weser and Musich from Hawaii to Kodiak.

The primary scientific objective of the Deep Sea Drilling Project is to investigate the origin and history of the ocean basins. Much of the project's emphasis has been placed on investigation of the system of continental drift and sea-floor spreading; that is, the creation of oceanic crust and its motion and assimilation into the earth's interior. In addition to the studies of these major structural features of the earth, investigations of the cores are yielding an unprecedented insight into numerous other fields, such as geophysics, inorganic and organic geochemistry, paleo-oceanography, paleoclimatology, glacial geology, faunal and floral evolution, sedimentology, biostratigraphy, volcanology, and mineralogy.

The scientific highlights for Fiscal Year 1971 include the drilling of salts and other evaporities in the Mediterranean Sea that led scientists to the conclusion that this sea had dried up for a period of about five million years. On the following leg, which traversed the Atlantic Ocean, diapiric structures were drilled off the coast of Africa. These structures were previously interpreted as being composed primarily of plugs of salt; however, drilling did not reveal any evidence of salt, but encountered igneous rocks covered by typical deep-sea sediments.

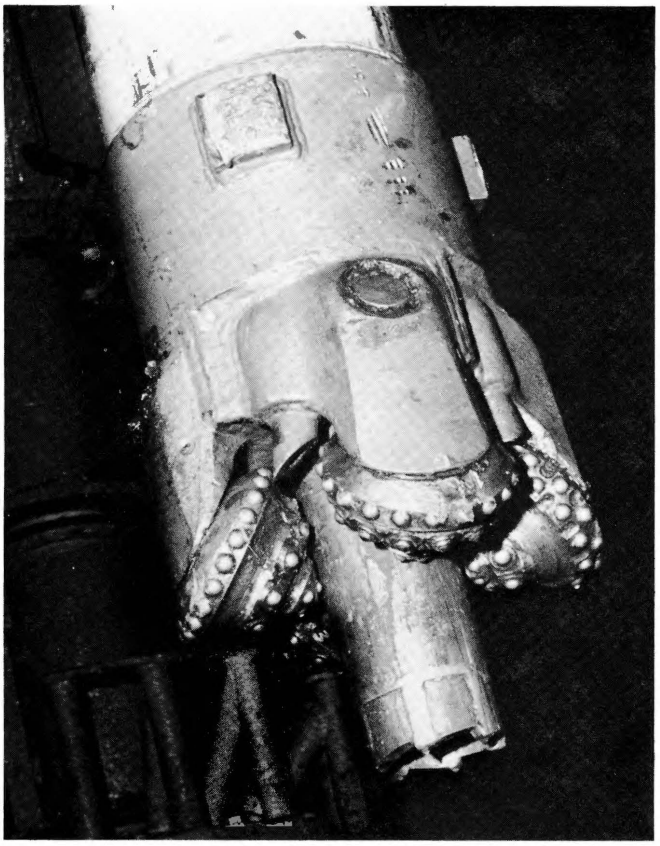
In the Caribbean Sea, the hole re-entry system was utilized for the first time in an attempt to achieve a scientific objective. In this case, from a hole continuously cored in the central part of the Caribbean, there was recovered a complete section of sediment from the Recent to the Upper Cretaceous, or from about 85 million years ago. These ancient sediments may lie on the top layer of the crust of the Caribbean and, if so, they are surprisingly young. In fact, they are much younger than the age of the rocks found on the circum-Caribbean lands. These results, although enigmatic in terms of previous concepts, now provide for the first time a foundation for geologists to reconstruct a logical sequence of events.

It has long been known that the Isthmus of Panama formed a barrier between the Caribbean Sea and the Pacific Ocean only about ten million years ago. The scientists drilling west of Panama demonstrated that the most probable cause of the uplift of this former ocean floor was the interaction between the fragments of the ancestral Carnegie Ridge and the Middle America Trench.

Drilling in the central Pacific Ocean, scientists demonstrated that the Pacific Ocean floor had probably moved some 1,800 miles northward during the last 100 million years. During that time episodes of violent volcanic activity built volcanoes that reached the surface and then sank thousands of feet below the ocean surface. Holes drilled near the continental margin of northwestern United States and Canada yielded information concerning the structures and sediments where the ocean crust is believed to thrust beneath the continental margin. This was the first time that a major effort by the *Glomar Challenger* had been focused on this facet of sea-floor spreading.

The re-entry system designed to replace the drill pipe in a drilled hole in the ocean floor was tested in June, 1970, and was used to achieve a scientific objective in December, 1970. Development of better bits to drill through chert and basalt continued with the adoption of a tungsten carbide "button" bit with sealed bearings that has virtually eliminated the chert problem in deep-ocean drilling.

In order to continue these studies on a global scale, JOIDES scientists have proposed a new scientific program for three years. The scientists have placed an emphasis on drilling in the Antarctic waters complementary to the highly successful research program conducted on the Antarctic continent. Studies relating to the role of Antarctic in the continental drift system and the possible related glacial history are now underway in Antarctica and will be the prime targets for *Glomar Challenger* in the surrounding ocean



New core bit designed and fabricated by Marine Sciences Development and Outfitting Shop at Scripps overcomes problems and meets objectives of the Deep Sea Drilling Project. This design allows the inner core barrel to extend beyond the bit and recover relatively undisturbed sediment. It was used along the Pacific coast of the United States and recovered cores in areas where previously much of the core was washed away by the seawater used to remove excess cuttings from the bore hole.

waters. Drilling sites for the vessel have been proposed in the Ross Sea that will complement proposed drilling on the continental land mass under the National Science Foundation's Polar Programs. The Antarctic Sea is the source of most of the deep water circulation of the major ocean basins, a fact which has been found to have played a major role in the distribution of sediments on the ocean floor and possibly on the climatic variations. Scientists anticipate that deep coring in these southern waters will yield detailed information regarding the nature, origin, and history of this circulation that may relate to the movement of Antarctica into its present polar position.

In the Arctic, plans call for drilling as far north as Spitzbergen to probe into the early history of this northern frontier. On an earlier cruise in the North Atlantic, scientists discovered, by examination of the microfossils, that prior to the glacial ages, warm subtropical water flowed through the Labrador Sea. A more detailed study of ocean current patterns during the glacial and interglacial stages is proposed east of Greenland, an area which is a major waterway to the Arctic Sea.

Large segments of the earth's crust, or plates, that are in motion are characterized by a lack of volcanic or seismic activity that is identified along boundaries between crustal blocks. Exceptions are seamount chains or ridges that are thought to arise from deep-seated magma as the crustal plate moves past. Drilling in these areas may reveal evidence related to the nature of the upper mantle, variations in age and differentiation of the igneous rocks, and the absolute motion of crustal plates.

Geological Research Division

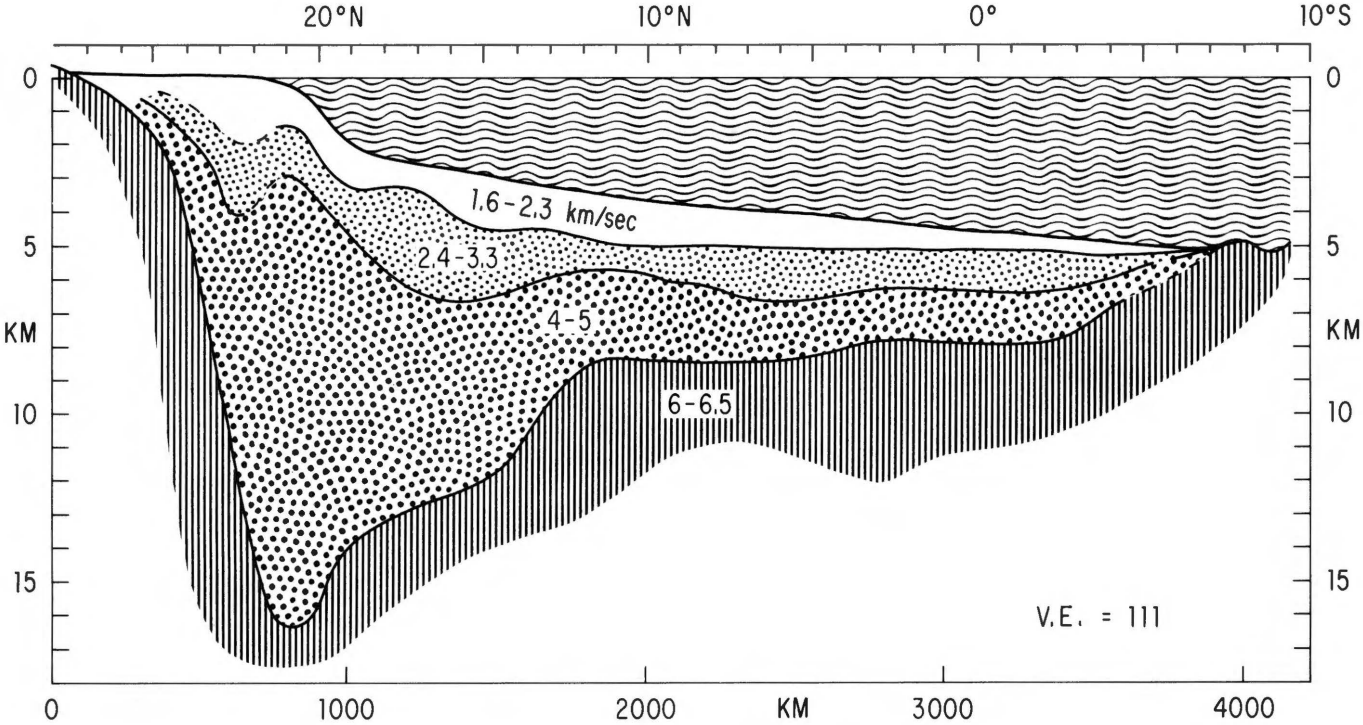
Drs. Joseph R. Curray and Russell W. Raitt, along with Dr. David G. Moore of the Naval Undersea Research and Development Center at San Diego, investigated the structure stratigraphy, sediment distribution, and geological history of the Bengal Deep-Sea Fan which underlies the Bay of Bengal, in the northeastern Indian Ocean. The sediments of this vast fan, the largest in the world, are derived primarily from the confluent Ganges and Brahmaputra Rivers and have come from erosion of the geologically recently uplifted Himalayan Mountains. Surface morphology of the fan shows a complex network of turbidity current channels. Surface sediment distribution was investigated by piston cores, and subsurface stratigraphy was investigated by a seismic reflection profiling and dredging of outcropping rocks.

History of this fan and the underlying sediments goes back approximately 100 million years to the time of separation of India from the other southern continents. Drifting of India northward from its former continental associates provided an oceanic basin into which the earliest sediments were deposited. Collision of India with Asia first occurred perhaps 50 million years ago, and this resulted in initial uplift of the ancestral Himalayan Mountains. Uplift of the modern Himalayan Mountains during the past 10 million years has resulted in the range now observed and the tremendous body of sediment filling the Bay of Bengal.

Deep seismic refraction studies made by Dr. Raitt and interpreted in the light of seismic reflection and other geological studies gives the preliminary transverse section of the Bengal Basin, East Pakistan at the north, across the Ganges-Brahmaputra Delta and Continental Shelf and down the axis of the Bay of Bengal to south of the equator. Seismic velocities (km/sec) were determined but age assignments must await deep-sea drilling by *Glomar Challenger* during early 1972. (See also Marine Physical Laboratory section.)

Drs. Curray and William A. Newman, in collaboration with Perry J. S. Crampton and Thomas F. Dana, continued studies on near-surface coral and algal reefs on both the north and south coasts of Panama. Particularly well developed terrace levels were found at depths of 120, 60, 37, and 18 meters. The present working hypothesis is that these terrace levels represent brief still-stands of the sea during the period of rising sea level from 15,000 to 3,000 years before present. The 18-meter level may, however, represent a period of reoccupation of a terrace inherited from a stand of the sea at or subsequent to the 120,000-year-high stand. Eustatic stands of sea level higher than the present have been postulated as having occurred within the past 5,000 years in many parts of the world. The San Blas Islands, off the north coast of Panama, have a discontinuous line of low-standing *Porolithon*-covered platforms on the seaward side of some of the islands, approximately 50 cm above mean sea level with many

Core of halite or rock salt with dark bands of anhydrite comes from the western Mediterranean Sea. Examining this and other evidence, scientists of the Deep Sea Drilling Project postulated the Mediterranean Sea dried up five to ten million years ago.



Scientists from the Geological Research Division investigated the structure stratigraphy, sediment distribution, and geological history of the Bengal Fan, which underlies the Bay of Bengal in the northeastern Indian Ocean. Longitudinal section summarizes geophysical determinations of sediment thickness.

coral heads clearly in growth position. Samples of the corals dated around 1,900 years before present, suggesting a high stand of relative sea level in this region. Tectonic stability of this region has not yet been established, however.

Dr. Newman, in collaboration with Arnold Ross of the San Diego Natural History Museum, also continued studies on the Antarctic Cirripedia. The first part of this work was published this year by the American Geophysical Union, as volume 14 of the *Antarctic Research Series.*

Dr. F. P. Shepard published *Our Changing Coastlines* (McGraw-Hill), with Harold R. Wanless, and the third edition of *Submarine Geology* was submitted for publication (Harper & Row). Continued studies with Neil F. Marshall of currents on the floors of submarine canyons showed that the alternating up-and-down-canyon flows have, in general, longer periods of reversals at greater axial depths. As studies have included three additional areas off California and Baja California, it was found that net downcanyon movement occurs at all localities. Also, more records at varying elevations above the canyon floors will be obtained with the Savonius rotors for future work.

Drs. Edward L. Winterer and Jerry L. Matthews continued their studies of the geologic history of the Pacific. Dr. Winterer participated as co-chief scientist on Leg 17 of the Deep Sea Drilling Project in the central equatorial Pacific, and Dr. Matthews was co-chief scientist on Leg 5 of Aries Expedition, from Honolulu to Tokyo. Dr. Winterer believes that the rate of northwest motion of the Pacific lithospheric plate over the past 40 million years, as derived from the successive positions of thick prisms of biogenous sediments deposited beneath the equatorial current system, is inconsistent with the rate of northwest motion implied by the age gradient of seamounts along the Hawaiian chain. This discrepancy suggests a southward motion of the asthenosphere beneath the Pacific plate.

Dr. Matthews dredged 15 seamounts along a more or less straight course from the western portion of the Mid-Pacific Mountains to the seamounts that lie almost directly east of Tokyo. Nine of the seamounts yielded faunas of rudistids and corals of Early Cretaceous age. Such a distribution of Early Cretaceous faunas over so broad a region of the Western Pacific is surprising in view of the predicted age of the crust from models of sea-floor spreading. This seeming paradox may be resolved in one of two ways: 1) the volcanoes formed on the flanks of almost west southwest-east northeast trending rise located approximately midway between the Shatsky Rise and the Mid-Pacific Mountains; 2) the volcanoes may be portions of chains of islands that formed above hot spots in the mantle. Careful dating with the fossils should resolve the problem or perhaps suggest an alternate solution.

Dr. Robert M. Garrels supervised the work of two PhD candidates. One is completing a thesis on the synthesis and stability of aluminosilicates at low temperatures, and the other is studying compaction of clay sediments in an attempt to relate porosity, diffusion coefficients, and osmotic behavior. A first-year student developed a mathematical model to explain the variations in the ratio of the stable isotopes of sulfur with time as found in evaporite deposits.

Dr. Garrels' interests are indicated by the publication (with Dr. Fred T. Mackenzie of Northwestern University, Evanston, Illinois) of *Evolution of Sedimentary Rocks* (W. W. Norton & Co., 1971). Also, in collaboration with Dr. Roland Wollast of the University of Brussels, Belgium, he determined the diffusion coefficient of silica in seawater.

Dr. Gustaf Arrhenius and his co-workers are investigating the chemical topography of the ocean floor to distinguish between those features that arise from sedimentation of matter carried into the oceans from the continents and those that are caused by the injection of matter from the deeper layers of the earth into the sediments and the deep-ocean water.

In order to obtain the chemical information required for this investigation, several years were spent developing an automatic X-ray energy dispersion spectrometer system capable of rapid and accurate chemical analysis of sediment samples. The instrument was designed and constructed by Ray W. Fitzgerald and Hitoshi Fujita, and during the past year it was completed to the point that it produces a visual display of spectral data. J. Greenslate analyzed in this manner several hundred core samples from

an East Equatorial Pacific test area, and the analyses already reveal interesting correlations between topographical features and element abundance. The spectrometer system was also used to help staff members of the Deep Sea Drilling Project identify unknown materials recovered in drilling operations.

A computer storage bank of ocean sediment data was developed by Jane Z. Frazer. This is designed to process, store, and retrieve analytical data obtained with the new instrument as well as data from other sources. In addition to storing chemical information, an important purpose of the data bank is to store information on samples collected that can potentially yield such information. As our actual analytical program is still in the test stage, the bulk of the information presently stored in the data bank consists of qualitative descriptions of more than 38,000 samples.

A sediment distribution atlas of the Mediterranean Sea was printed, and corresponding charts of the northern hemispherical part of the Pacific are approaching completion.

Work on returned lunar samples attempts to reveal significant aspects of the surface evolution of the Moon during the first half of the history of the solar system. This two-billion-year period is virtually unrecorded on earth. One of the particular aims of this work, being done with UCSD Professor Hannes Alfvén, is to establish the boundary conditions for the early state of the surface of the Earth and to obtain insights on the possible origin and early evolution of the oceans.

Dr. Devendra Lal spends one-quarter of his time at Scripps and the remainder at Tata Institute of Fundamental Research, Colabra, India. He and his co-workers employed the fission track dating method as a tool for understanding several problems of importance in marine geology. These are (1) the chronology of ash layer sequence in sediments and related implications (volcanic history of certain areas of the ocean basins, sedimentation rates, etc.) and (2) absolute dating of various features of the ocean floor, including ridges, seamounts, and abyssal hills as well as the abyssal ocean floor itself through samples recovered by the Deep Sea Drilling Project. Necessarily a great deal of development work was required for these projects, since fission track studies constituted an entirely new field of research for Scripps when they were begun in late 1969.

Work carried out during the past year by graduate student J. Douglas Macdougall shows that fission track dating of glass shards in volcanic ash layers is a reliable and fairly generally applicable method for sediment age determination. This work continues. Ash layers from several volcanic areas sampled during the Deep Sea Drilling Project are under study by Macdougall.

The fission track work on basaltic rocks from the ocean floor began because no other known dating method is applicable to the majority of rocks recovered. Most potassium-argon dates from oceanic rocks are suspect because of the inherited argon problem (high hydrostatic pressures existing on the sea floor do not permit lavas to degass as they do at atmospheric pressure) or because of alteration effects. Fission track studies to date have both added valuable information to local geologic studies of Dr. James W. Hawkins, the late Dr. Edwin C. Allison, and Macdougall and have given some insight into more general aspects of volcanism on the sea floor.

Another aspect of fossil track work currently underway at Scripps concerns the effects of cosmic radiation on lunar rocks and soils. New techniques were developed for high contrast and high resolution study of fossil tracks. Drs. Lal and Arrhenius are using records of radiation history in the form of particle tracks to study dynamic processes on the moon's surface, as well as to study the past and present composition and energy spectrum of the cosmic ray beam. Using similar methods, Dr. N. Bhandari and colleagues at Tata found evidence for extinct transuranic and superheavy elements in meteorites and lunar soil grains.

Experimental and theoretical work continued to estimate the nature and magnitude of *in situ* contribution to dissolved trace elements in seawater by the particulate matter transiting through a vertical column in the oceans. The existence of a man-made C^{14}-labeled sinking chronology of biogenic calcareous particles was discovered as a result of experiments carried out in the South Pacific during Nova Expedition in 1967. Realizing the great importance of the *in situ* processes, both toward understanding the trace element budgets as well as toward applying C^{14}, Si^{32}, and Ra^{226} as tracers for evaluating the parameters characterizing the large scale circulation of water, scientists planned new experiments, including the isotopes Fe^{55}, C^{14}, Si^{32}, and Ra^{226} to establish overall patterns for a suite of elements. Theoretical calculations based on oversimplified models involving Stokes's settling of particulate biogenic matter were initiated to understand experimental data *on dissolution*. The work was carried out in collaboration with graduate student Sharon A. Stonecipher, B. L. K. Somayajulu, and Dr. John Edmond.

Dr. Harmon Craig's work during the year was principally occupied with the Geochemical Ocean Sections Study (GEOSECS), established March 1, 1971, as the first major program of the International Decade of Ocean Exploration sponsored by the National Science Foundation.

By measuring oceanic parameters along Arctic-to-Antarctic tracks throughout the water column, GEOSECS scientists will provide, for the first time, a detailed set of physical and geochemical data on the same water samples. These data will provide the input for quantitative studies of oceanic mixing, and they will serve as a base line for the levels of certain pollutants and waste and fission products being added to the sea.

Participating institutions in GEOSECS are Scripps, Lamont-Doherty Geological Observatory of Columbia University, Palisades, New York; Woods Hole Oceanographic Institution, Massachusetts; Oregon State University, Corvallis; University of Miami, Florida; University of Washington, Seattle; and the University of Hawaii, Honolulu. Additional programs being planned by West Germany, Japan, France, and other nations will explore supplementary ocean sections.

Dr. Craig is a member of the three-man executive committee which is responsible for the overall execution of the program. Others on the committee are Drs. Wallace S. Broecker of Lamont-Doherty and Derek Spencer of Woods Hole.

Capital equipment for the shipboard analytical and hydrographic program for GEOSECS is being constructed under a grant to Dr. Craig, Joseph L. Reid, and Arnold E. Bainbridge, and an operations group for carrying out the work at sea is being assembled under Bainbridge. (See Ocean Research Division for details.)

Dr. Craig, together with Fred S. Dixon and Yu-chia Chung and Drs. Lal and Ray F. Weiss, is developing the following six programs: (1) construction of a new hydrographic winch and a new-type balanced conducting wire for deep STD measurements to 10,000 meters; (2) shipboard gas chromatography with thermal conductivity and ultrasonic detectors for analysis of dissolved total CO_2, N_2, and Ar at sea; (3) stable isotope analyses for H^2, O^{18}, and C^{13} in seawater, atmospheric and dissolved CO_2, water vapor, and dissolved O_2; (4) measurements of dissolved rare gases He and Ne, and He^3/He^4 ratios; (5) Ra^{226} measurements; and (6) sampling equipment and methods for Si^{32} profiles to be analyzed by Dr. Lal's group at Tata Institute, Colabra, India.

During the year, the results of work at the first GEOSECS intercalibration station accomplished in 1969, 400 miles southwest of San Diego, were published in a special issue of *Journal of Geophysical Research*. A second intercalibration station was occupied late in 1970 in the North Atlantic, on R/V *Knorr*, an oceanographic research vessel operated by Woods Hole Oceanographic Institution. In 1971, the group will test the new winch and STD system during Antipode Expedition in the South Pacific and operate another series of sea trials off Baja California from aboard R/V *Melville*.

The first expedition, in the Atlantic, is scheduled to begin at Woods Hole in July, 1972, on WHOI's R/V *Knorr*. This first expedition calls for the occupation of 70 oceanographic stations along the main survey track. At each station vertical profiles of approximately 50 samples will be taken with each sample measuring about 30 liters. At some of these stations, 1000-liter samples will also be taken at about 20 depths for measurement of trace elements and low concentration radioisotopes. Some stations will be sampled for Si^{32} using sponge or fiber *in situ* filters. Before this expedition ends in March, 1973, stops will have been made in Reykjavik, Iceland; Bridgetown, Barbados; Recife, Brazil; Buenos Aires, Argentina; Punta Arenas, Chile; and Cape Town, Union of South Africa.

Much of the analytical work will be done directly on R/V *Knorr* and, during Pacific Ocean investigations in 1973–74, on Scripp's R/V *Melville*. The remaining analyses will be accomplished in the laboratories of participating geochemists throughout the country. A "water library" of samples will be maintained at Woods Hole for future work.

Dr. Chung's research in 1970–71 was concerned with the deep- and bottom-water properties and circulations based on temperature data (thermistor and thermometric) and various oceanographic and geochemical tracers. Distributions of tracers were predicted from the theoretical studies on the dynamic circulation model and the two-dimensional diffusion-advection model. Analyses of temperature profiles from the Pacific enabled him to map the spreading and various characteristics of the Antarctic bottom water in the Pacific.

Dr. Chung's radium profiles from the Pacific and Atlantic GEOSECS intercalibration stations and those from Scripps's Scan Expedition in the eastern equatorial Pacific show that the radium content of the Pacific deep water is greater than that of the Atlantic deep water by a factor of three. The measured values and the trend of increase suggest that the radium input by both particulate matters and by feedback by diffusion from sediments must be greater than the mean radioactive decay by at least a factor of two. The particulate input, as estimated from the vertical diffusion-advection model, is negligible in general and at most is equal to the radioactive decay term. Thus, the feedback of radium from sediments must be the major source of radium input in the deep water of the world ocean.

Dr. Weiss is concerned primarily with the study of dissolved gases in seawater and with preparations for this aspect of GEOSECS. Gas chromatographic techniques were developed for precise shipboard analysis of dissolved N_2, O_2, Ar, and total CO_2, and an extensive multi-institutional study of the dissolved carbonate system established the accuracy of this method.

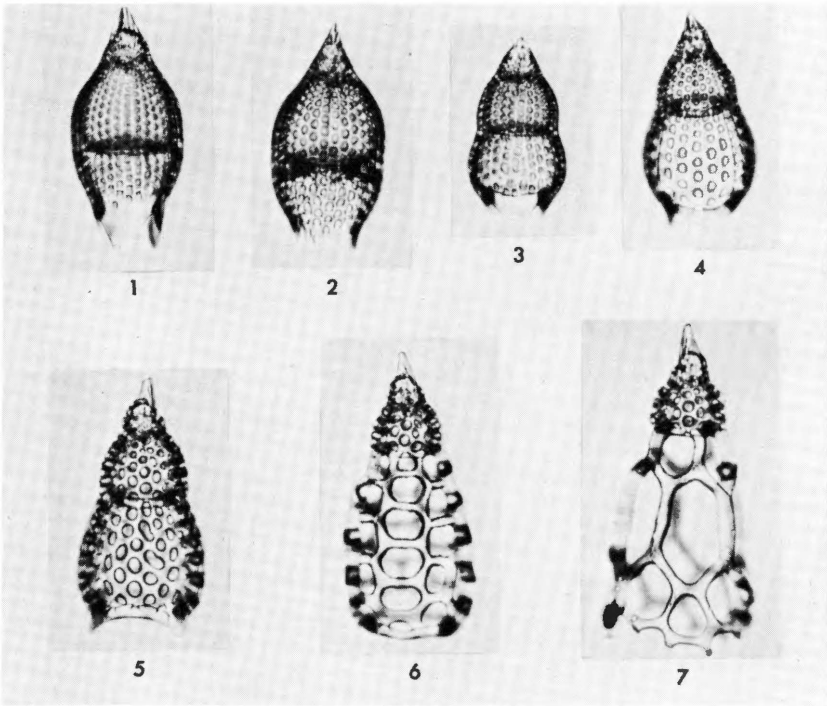
Dr. Weiss continued his work on the solubilities of gases in seawater, including new measurements of the solubilities of He and Ne, which showed that air injection processes, rather than geophysical sources, are responsible for a major fraction of the excess He found in deep-ocean waters. As an extension of these studies, he is also working with the Environmental Protection Agency on gas supersaturation in the Columbia River—a problem which threatens the survival of salmon and other fishes. In addition to its obvious environmental importance, this work provides a valuable outdoor laboratory for the study of atmospheric exchange processes.

Research programs of Dr. Edward D. Goldberg, Dr. Rudolf H. Bieri, John J. Griffin, and Minoru Koide are concerned with the transfer of solid materials from the continents to the oceans, with the transfer of noble gases from the atmosphere to the oceans, and with the subsequent fates of such materials in the marine environment. Emphasis is placed upon those materials introduced as a result of the activities of man.

One principal thrust involved the measurement of mercury, sulfur, and selenium fluxes as a result of man's activities and comparison with the natural rates of entry. Fallout of these species over the past two thousand years was recorded in the strata of a Greenland ice sheet which provided Scripps with the samples which have been subjected to slow neutron activation and visible spectroscopic analyses. The mercury and sulfate contents in the glacial materials indicated significantly higher rates of deposition in recent years; the mobilization of the substances is attributed to landscape alteration and fossil fuel burning.

Precision analyses of the noble gases—helium, neon, argon, and krypton—in seawater indicated that states of supersaturation in deep waters can be uniquely attributed to the dissolution of air bubbles. A 12 percent excess of helium was found in deep- and bottom-waters of the southeastern Pacific Ocean. This confirms previous results and more firmly establishes the concept of an influx of this gas through the crust of the earth from the decay of uranium and thorium nuclei.

The sources and transport paths of sedimentary particles were sought for the Lau Basin in the South Pacific, a most unique sedimentary environment. Although the non-biological phases are solely volcanic debris or their degradation products, the Lau Basin sediments are rapidly accumulating compared to the neighboring South Pacific sediments.



Geological Research Division scientists study evolution of radiolarian microfossils as a basis for assigning ages to ocean sediments. In a number of genera, a characteristic which may provide a clue to the factors guiding evolution is the rectilinearity of change, as in this example of the lineage from Podocyrtis papalis *(Fig. 1) to* P. goetheana *(Fig. 7), with which the series became extinct. This series spans the entire Middle Eocene, a duration of almost six million years.*

For his PhD thesis, Thomas M. Church completed the first extensive geochemical investigation of marine barite (barium sulfate). The study indicated that the mineral results from the concentration of barium in marine organisms and the subsequent precipitation of its insoluble sulfate during the degradation of organic matter. The marine barites are substances of exceptional purity compared to other oceanic precipitates. The intermediate waters of the eastern Pacific are saturated with barium sulfate, as are the pore waters of sediments.

In the past year Frances L. Parker studied the Late Tertiary planktonic foraminifera from Atlantic deep-sea cores and from core material recovered during Legs 1, 2, and 4, of the Deep Sea Drilling Project. A report on this work was submitted to the Committee on Mediterranean Neogene Stratigraphy.

A study of the distribution and solution patterns of planktonic foraminifera in the surface sediments of the North Pacific is almost completed. This study will complement the work previously done on the South Pacific. A similar study of Indian Ocean surface sediments is in the early stages. The Tertiary planktonic foraminifera of a small area in the equatorial Pacific were studied and results will be published in conjunction with a report on the Radiolaria.

Dr. Fred B Phleger continued studies of the applications of foraminifera to various problems of oceanography based on their distributions and ecology. Studies of foraminifera associations in Mexican coastal lagoons have shown the following: 1) very long lagoon inlets (8–10 km) modify the invading marine water so that only inner lagoon and marsh environments occur within such lagoons as reflected by the foraminifera; 2) in two different lagoons each having two inlets (Terminos and Huizache-Canimanero Lagoons), patterns of foraminiferal populations were used to demonstrate a net flow of water in one inlet and out the other, a fact later verified by other observations; and 3) in Etchoropo Lagoon, which was artifically flooded with seawater and irrigation water, the rate of invasion of foraminifera was very

fast, with large standing stocks of foraminifera being established within three months and with reproduction having occurred. Large standing stocks were interpreted as related primarily to hypersaline conditions. Large populations of mullet and shrimp also were established during this period.

An analysis was made of Late Pleistocene records of foraminifera in deep-sea cores in an attempt to reconstruct oceanic conditions during a glacial stage. The PhD research of David A. Johnson demonstrated significant post-Miocene and pre-Holocene deep-sea erosion in his study area; this was attributed to an increase in intensity of deep-sea bottom currents during a glacial stage.

William R. Riedel continued to investigate radiolarians in cores collected from the open oceans by regular oceanographic expeditions, in outcrops on land, and in long, continuous sequences cored by the Deep Sea Drilling Project. These studies have advanced the understanding of this group of microfossils to the extent that radiolarians can now be reliably used for precise correlations and age-assignments of low-latitude sediments, and approximate correlations of high-latitude deposits, through most of Tertiary time. Riedel and Annika Sanfilippo have traced the course of evolution of many radiolarian genera and have therefore been able to change portions of the system of classification of this group of planktonic microorganisms so that it now more closely reflects natural relationships.

In a number of radiolarian genera, the nature of the evolutionary change has three characteristics that may provide a clue to the factors which guide evolution in this group of single-celled organisms: 1) evolutionary change (as expressed by skeletal morphology) apparently occurs as a continuum and not step-wise; 2) the change is often rectilinear, i.e., there is a continuing trend of morphological change in the same direction, as exemplified by the increase in size of the pores in the third segment and by decrease in size of the second segment, through time; 3) in lineages which have become extinct, the terminal member commonly has a bizarre form (with characters "abnormal" for the group to which it belongs).

A possible explanation for these observations is that an evolutionary trend was initiated in response to some environmental pressure and then continued with a kind of inertia or innate momentum until the tendency led to a form completely out of balance with its environment, which then became extinct. Such an inertial component of evolutionary change, acting independently of the forces of natural selection, is not readily compatible with theories of evolution generally accepted today.

The possibility of using microscopic skeletal debris such as teeth and scales of fishes to correlate pelagic sediments is being investigated by Phyllis B. Helms. These are the only microfossils present in many deep-sea clays.

The main research activities of Dr. James W. Hawkins are studies of metamorphic and volcanic rocks of present day and ancient ocean margin environments. Volcanic rocks of the Lau Basin-Tonga Arc area in the southwestern Pacific were studied in an effort to determine the petrologic processes operating behind volcanic arcs in zones of active crustal consumption. The Lau Basin, on the concave side of the Tonga Arc, is characterized by thin sedimentary cover, elevated topography, and a series of basalt ridges. The basalts are chemically and mineralogically like oceanic-ridge basalts. The geologic studies, supplemented by geophysical work done by Dr. John G. Sclater, support the concept that the Lau Basin is an area of crustal dilation, even though the adjacent Tonga Trench is an area of crustal consumption.

Metamorphosed volcanic and plutonic rocks of southern California were studied to determine their geochemistry, mineralogy, and tectonic setting. These rocks indicate that there was a zone of silicic volcanism and plutonism and high pressure metamorphism along coastal southern California in Late Mesozoic time; this rock assemblage is good evidence for a zone of crustal consumption. These units have essentially the same age as similar rock series known in northern California and support the concept that most of western North America was a site of active crustal consumption during the Late Mesozoic.

Throughout the last year the research efforts of Dr. Albert E. J. Engel and his group concentrated on interpretation of mantle-crust environments from fractionation indices K/Na for igneous and sedimentary rocks and from secular features of orogenesis, especially tectonic patterns in the Permian Pangaea. It was found that sedimentary and igneous K/Na increase abruptly from Archean to the Late Proterozoic, fluctuate irregularly to the Triassic in variously stepped, indented, subhorizontal curves, then plunge abruptly to near Archean lows (0.4–0.7). The lows are coincident with the on-set and major episodes of post-Permian, large-scale continental fragmentation and drift.

Reconstruction of Archean orogenic belts in Pangaea indicate a coalesced megafabric of subparallel orogenic belts, spreading centers, and subduction zones. These appear to have retained this approximate interrelationship from Archean to the Cenozoic.

These data suggest that the post-Permian fragmentation and widespread drift ($>$ 2000 km) of large continental fragments are unique. The accordant east-northeast Archean megafabrics and low K/Na indicate widespread evolution and systematic migrations of Archean arcs, spreading centers, and protocontinents. But the major Archean and relative subordinate Proterozoic rifts and drifts, were largely accretive with accompanying continental fragmentation. Paleozoic movements were incipiently dispersive; post-Permian ones, hemispheric.

Latitudinal motions dominated Archean global tectonics and persisted in southern Gondwanaland into the Mesozoic. This fact would seem to argue against global tectonics as a function of or largely influenced by differences in rates of rotation of the earth. Motivating energies and motions appear to be largely of internal origin and cause.

A biosphere is recorded in the oldest Archean rocks, hence the origins of life precede the recognizable rock record.

Dr. Robert L. Fisher and colleagues continued the analysis and field relation interpretation of the rock samples, bottom photographs, topographic, and magnetic and sediment thickness data collected on his portions of the 1968 Circe Expedition (western Indian Ocean: mid-ocean ridge systems), 1969 Quebrada Expedition (Eastern tropical Pacific: East Pacific Rise), and 1970 Seven-Tow Expedition (Tonga Trench: deep walls). This laboratory petrographic work is being carried out in collaboration with U.S. Geological Survey scientists, most notably Dr. Celeste G. Engel. A 50-minute sound film, New Odyssey, on the 1968–69 round-the-world Circe Expedition was completed and has been used by various Scripps and agency scientists before university and lay audiences.

As for field work, Dr. Fisher served as cruise coordinator of the 15½-month, 61,000-mile Antipode Expedition and spent early October through mid-February aboard R/V *Melville* in the western Indian Ocean. His geological-geophysical field program was designed to extend and detail the 1960, 1962–63, 1964, and 1968 investigations of the mid-oceanic ridge systems and aseismic submarine plateaus of the region.

These Antipode investigations in the southwestern Indian Ocean were carried out in cooperation with field geophysicists of the Institut de Physique du Globe, Paris, and of the Bernard Price Institute, Johannesburg, Union of South Africa. In the late 1970 period R/V *Melville* experienced difficulties in her propulsion, steering, and winch systems. The resulting underway operating speed of six to seven knots made for excellent bathymetric and airgun records, but severely limited the magnetic surveys. Nevertheless several cross-fractures were delineated topographically and magnetically and then dredged in some detail.

Sixteen successful dredge hauls and three camera stations were made on the Central and Southeast Indian Ridge and in associated cross-fractures; those dredge hauls are remarkable for the range and quantity of obtained coarse-grained mafic and ultramafic rocks, both fresh and serpentinized. Evidences of dynamic metamorphism and hydrothermal mineralization were abundant in the cross-fractures. Nine dredge hauls on the less-active Southwest Indian Ridge yielded similar rock species, but with a higher proportion of serpentinites than to the north and east. On the portion of the Southwest Indian Ridge explored by R/V *Melville*, the crestal segments trend nearly east-west (consistent with north-south spreading) and are cut by deep but sediment-mantled cross-fractures (transform faults) trending almost north-south.

Following major repair and replacement of after-cycloid gears at Mauritius in December, R/V *Melville* regained her 10½-knot speed so that underway programs again became a large part of the program. R/V *Melville* worked north along the Central Indian Ridge and onto the Mascarene Plateau between Seychelles

and Saya de Malha. Seventeen successful dredge hauls were made on the ridge-and-cross fracture system and on the deep portion of the fossil reef-covered Mascarene Plateau. Four Deep Sea Drilling Project sites for expected drilling by *Glomar Challenger* in May–July, 1972 were scouted and sampled.

Dr. Jacqueline Mammerickx-Winterer completed work on the morphology of the Aleutian abyssal plain, showing that it is a coalescing fan built by several channels issued from a northern source. The various channels may have come from a unique source of sediments and developed successively from west to east as the Pacific plate moved toward the Aleutian Trench. Work was initiated on a set of ten bathymetric charts covering the South Pacific. The two first sheets covering the area from Australia to Samoa are completed. Detailed studies of two areas were made: the Lau Basin and the New Hebrides island arc and inter-arc basin.

Stuart M. Smith studied the recently discovered Magellan Rise, located at 7°N, 177°W, which has many similarities with the previously known Shatsky and Manihiki Rises in the western Pacific. In association with Uta G. Ritter and George Sharman, he continued the project of digitizing the navigation, depth, and magnetic data from Scripps. Updated indices of these data are reported in SIO Reference 71-6.

In the fall of 1971, Smith will join the Geological Data Center with the responsibilities for coordinating the underway geological data processing. He has also been involved in the design of a general sample index for all data collected at sea by Scripps.

Under the direction of Thomas E. Chase, the Geological Data Center prepared one series of ten colored bathymetric charts of the North Pacific and a single composite chart of the topography of the North Pacific. The Center is also compiling index charts of bathymetry, magnetics, and seismic reflection in the Pacific Ocean. The storage of original records on 35 mm microfilm is commencing. In addition, copies of all records will be reduced and put onto Mylar base material for ease of duplication.

Marine Biology Research Division

Investigations in the Marine Biology Research Division embrace a wide range of experimental and descriptive biological disciplines, including physiology, biochemistry, microbiology, developmental and systematic biology, and ecology of the sea. Experimental approaches emphasize fundamental biological processes which are accentuated in marine organisms and their environment. The studies, which are often comparative in nature, examine structures, events, or processes in a wide range of organisms, both marine and terrestrial. New insight into fundamental problems of biology and medicine is gained by a better understanding of marine organisms and the manner in which they adapt to life in the sea. The work of the Division is described below.

The biology and metabolism of wax has proved to be central in the metabolic economy of the sea. The discovery in the laboratory of Dr. Andrew A. Benson that most copepods convert their dietary triglycerides from diatom and dinoflagellate algae into wax esters has engendered numerous biological oceanographic, physiological, metabolic, and biochemical studies. Wax accumulation and utilization by copepod species from the polar seas, from tropical waters, and particularly from local and northern temperate areas has clearly revealed the fact that wax production is the means by which copepods can survive long periods of starvation. As much as 70 percent of the animals' dry weight can be liquid wax esters. Their chemical composition has been related to dietary triglyceride composition. Wax synthesis has been effected in the laboratory by using enzymes derived from copepods. Wax degradation has been studied by using lipolytic enzymes found in the pyloric secum of young salmon and other small fishes which feed on copepods.

Metabolic toxicity studies on hydrocarbons and chlorinated compounds have revealed important metabolic mechanisms and sites of action, particularly in molluscs and fishes. The results have a bearing on the distribution of copepods in polluted waters and upon the role of some cancer-inducing agents in higher animals.

A novel phospholipid has been discovered in copepods. It contains an extremely unsaturated (22:6) acid amide in an ethanolamine sphingomyelin, quite unlike any previously reported sphingolipid.

The production and distribution of large amounts of polyunsaturated hydrocarbons in marine algae have been subjects of much laboratory investigation. Their possible role as chemical signals in guiding fish migration should be investigated.

Investigations of the effects of photo-environment on the behavior of mesopelagic animals that undertake extensive diurnal vertical migrations and on the evolution of vision in these animals are being continued in the laboratory of Dr. Elizabeth Kampa Boden.

During 1971–72, a series of observations are planned to determine the degree of stability in the optical properties of the waters at depths greater than 100 meters in a given area of ocean. It had been assumed that, below about 100 meters, the attenuation of light with depth was the same for all oceanic regions. Past work has shown that such an assumption is wrong and that a wide range of attenuation coefficients exists in the waters of the various oceans even below 200 meters. During the course of the studies both constant environments and dramatically changed light regimes have been observed.

The present study is intended to extend such observations in time, so that the validity of interpreting the behavior of the photo-oriented diurnal vertical migrants in terms of *in situ* light measurements made in the same region in other years can be assessed.

Two interesting facts have emerged already. The region first selected was an area in the San Diego Trough just north of the Coronado Islands, one that had been studied in June, 1955. At that time the 10^{-5} μ W isolume at 470 nm (nano meter) occurred at about 350 meters at midday. In June, 1971, this midday value was observed at a depth of 225–250 meters, indicating that some significant change occurred in the optical properties of this water mass during the 16-year interval. Also, it was observed that the bioluminescence in this region had been greatly reduced since 1956 measurements. It is suspected that these alterations can be attributed to an increase in pollution of this relatively near-shore environment.

A program to study mechanisms of transport of water, electrolytes, and respiratory gases in intact animals and tissue preparations is being conducted by Dr. Theodore Enns. Rosemary A.

Electron micrograph shows spermatozoon of the crinoid Florometra *collected in 500 feet of water about ten miles west of San Diego and belonging to marine biologist Dr. Nicholas D. Holland.*

Thompson is completing her thesis research on electrolyte transport in euryhaline fish. Gerald W. Bowes's PhD research dealing with the effect of DDT on photosynthesis and respiration in marine phytoplankton was completed in 1971. An extensive study on the role of carbonic anhydrase in carbonate transport led to examination of the role of DDT as an inhibitor of carbonic anhydrase. The new information shows that DDT in concentrations of several parts per billion is sufficient to inhibit carbonic anhydrase activities such as those reported by Bowes for marine phytoplankton. Such inhibition has not yet been demonstrated in living organisms, perhaps because it is generally assumed that very large amounts of DDT were necessary to achieve it. The role of myoglobin in the buccal muscle of *Aplysia californica* in the transport of oxygen is also being studied.

The earliest stages of development, especially oogenesis and fertilization, are being actively studied by Dr. David Epel and his colleagues. Research with Dr. Victor D. Vacquier, Jr., and Laura A. Douglas has centered on the role of a trypsin-like protease which is released by eggs upon insemination. This enzyme, present in the cortical granules, is involved in elevating and forming an extracellular membrane (fertilization membrane) that surrounds the eggs at fertilization. This membrane prevents the entry of more than one sperm and is a major component of the block to polyspermy.

Dr. Epel and Elizabeth Baker are currently examining the activation of an amino acid transport system which becomes active five minutes after insemination. This transport system is dependent on Na^+ and has a low requirement for metabolic energy. Using this system, the embryo can accumulate appreciable amounts of amino acids at the low levels present in coastal waters (10^{-7} to 10^{-8} M). This ability may be a general characteristic of marine embryos, and the adaptive value of amino acid transport is being investigated.

Dr. Vacquier continues his studies on the control of synthesis of digestive enzymes in sand dollar larvae. He has found that two enzymes, a B-1, 3-glucanase and an χ-amylase, begin to be made at the time of gut differentiation. One of these enzymes is repressed by its end product (glucose), and provides an excellent model system for studying embryonic differentiation.

Dr. Denis L. Fox, professor emeritus of marine biochemistry, spent the year as Distinguished Scholar at the Cranbrook Institute of Science in Bloomfield Hills, Michigan. There he was active in writing and in lecturing. He was also consultant for the Institute's Lake Research Program.

His research interests in biochromes and color phenomena were extended there to two species of land plants. In collaboration with Dr. James R. Wells, staff botanist at Cranbrook, he investigated the physical basis for a changeable blue interference coloration in the primitive pteridophyte *Selaginella willdenovii* and the carotenoid composition of two geographically separated species of a composite plant *Polymnia,* and in their hybrids. Dr. Fox now continues his researches here on the pigments of marine invertebrates, especially corals.

Ralph V. Dykes, a graduate student in marine biology, is studying the ability of intertidal gastropod molluscs of the genus *Littorina* to resist experimentally imposed environmental extremes of temperature, desiccation, and elevated tissue-salt concentrations.

Dr. Francis T. Haxo and colleagues continued studies on photoreactive pigments and photoecology of algae. Laboratory mass culture methods were applied with considerable success to the dinoflagellate algae, which are usually obtainable in abundance only during the occasional red tide. In collaborative studies with three other laboratories (Dr. H. H. Strain, Argonne National Laboratory, Argonne, Illinois; Dr. S. L. Jensen, Trondheim, Norway; and Dr. Henry Rapoport, University of California, Berkeley), peridinin, the characteristic carotenoid of dinoflagellates, was isolated in the pure form and its novel structure determined.

While he was on sabbatical leave at Brookhaven National Laboratory, Upton, Long Island, New York, Dr. Haxo collaborated with Dr. H. W. Siegelman of that laboratory and Dr. G. F. Somers, University of Delaware, Newark, in the isolation and characterization of a peridinin-chlorophyll *a* complex from the dinoflagellate *Cachonina niei.* Molecular weight, subunit size, amino acid composition, and chromophore contents of this unusual chromoprotein were determined. Preliminary evidence indicates that energy is transferred from peridinin to chlorophyll *a.* It is believed that the complex functions as a light-harvesting pigment for photosystem II of photosynthesis. Comparative studies on dinoflagellates and other brown-colored algae continue with a view to elucidating the properties, localization, and role of carotenoid-protein-complexes in the photochemical processes of these dominant components of the phytoplankton.

Dr. Katherine Y. Bowen has completed a doctoral dissertation on the light-growth relationships in the deep water red alga *Maripelta rotata* and has demonstrated for the first time in a red algae a requirement for light in chlorophyll formation.

Laurel Loeblich has obtained evidence that, at high salinities, growth of the halophytic algal flagellate *Dunaliella salina* is limited by the availability of CO_2 and that activity of the enzyme carbonic anhydrase may be of importance in the growth of *Dunaliella* under these conditions.

The activities of Dr. Robert R. Hessler are divided between two general topics. The study of deep-sea benthic communities continued to concentrate on population structure of the oligotrophic bottoms under the central gyres of oceanic circulation. Replicate samples from the North Pacific gyre revealed a fauna which is quite uniform at a higher taxonomic level; however, the low faunal density in this area, coupled with a very high faunal diversity, causes the species composition of each sample to be quite variable.

Dr. Hessler's laboratory is also active in studies of marine crustaceans. The work includes systematic studies on cephalocarids and deep-sea isopods, as well as an inquiry into the question of the origin of the crustaceans.

Current research by Dr. Nicholas D. Holland includes electron microscopic studies of several organ system in the classes Echnoidea and Crinoidea of the phylum Echinodermata. Organs under investigation in echinoids are the mucus-producing regions of the digestive tract and the poison glands of the globiferous pedicellariae. Organs under investigation in crinoids are the ovaries, testes, axial organ, podial papillae, saccules, and chambered organ. The electron microscopy of such organs not only brings to light their detailed anatomical structure, but also gives fresh insight into their functions. Another current project is the autoradiographic study of the time course of spermatogenesis in crinoids following administration of tritiated thymidine. The growth of oocytes during the annual reproductive cycles of several echinoid species is also being investigated.

Dr. Carl L. Hubbs and his associates continued varied researches on marine vertebrates and on paleoecology. Two publications were completed on lampreys: one, an account of a new species, the nonparasitic derivative of the Pacific lamprey; the other, a general account of the systematics, distribution, and phylogeny of the lampreys of the world, to appear as the first chapter in *The Biology of Lampreys.* With international cooperation the systematic study of the hagfishes of the West Coast was expanded into a world revision; it appears that the known species of these most primitive vertebrates will be increased at least one-fourth, and much information is accumulating on the distribution and biology of these creatures.

Two co-authored papers on fur seals were prepared for publication in the *Antarctic Research Series:* one, on the teeming original abundance, near extinction, and survival of the Juan Fernandez fur seal; the other, on the systematics of the southern fur seals *(Arctocephalus).*

A detailed account of the paleohydrographic history and the remnant fish fauna of the north-central Great Basin was completed for publication as a *Memoir of the California Academy of Sciences.* More exposures of the fossil deposits on Isla de Guadalupe were discovered and collections made toward an analysis of the northward spread of animals during the Sangamon Interglacial.

Additional studies were conducted on the systematics and biology of the marine vertebrates, particularly along the West Coast. Expeditions off Baja California in the "MV" (Marine Vertebrate) series were continued. A general account of the lanternfishes of the eastern Pacific was prepared for publication by the Navy by researcher Robert L. Wisner, along with descriptions of new species.

Dr. Benjamin E. Volcani, microbiologist in the Marine Biology Research Division, samples a culture of diatoms as part of his silicon investigations.

In the laboratory of Dr. Ralph A. Lewin during the past year, William F. Blankley completed his PhD research on coccolithophorids. These are unicellular planktonic algae, previously little studied in laboratory culture. Blankley isolated various strains of *Emiliana huxleyi* and of *Cricosphaera carterae,* and grew them under controlled conditions in axenic culture. In light, by photosynthesis, they grow and deposit mineralized scales (coccoliths) composed of calcite crystals in highly specific forms. Blankley showed they can do the same though at a reduced rate in darkness, if supplied with glycerol as substrate for heterotrophic metabolism.

Other work in this laboratory, carried out in collaboration with Marti L. Campbell, concentrated mainly on three subjects:

(1) Culture and nutrition of species of *Spirulina,* helical blue-green algae which grow commonly in marine aquaria. One species, *S. platensis,* has gained considerable attention in recent years as a possible source of microbial protein for domestic consumption. An isolate of this species, obtained from a marsh in nearby Del Mar, is being studied here and in other laboratories in France, Japan, and Mexico.

(2) A facultatively anaerobic gliding microbe (order Flexibacterales). This has been isolated from marine mud, and its physiology and nutrition are now under investigation. Since similar organisms, generally assigned to the genus *Fusobacterium,* are common denizens of the human mouth, the possibility of reclassifying them with the flexibacteria is being explored.

(3) Experimental studies on small brown seaweeds of the genus *Ectocarpus.* These algae grow well in the laboratory in pure culture, either in liquid or on agar media. A growth requirement in *E. siliculosus* for iodine has been confirmed; the iodine concentrations in normal seawater are apparently insufficient for its optimal growth. Morphological mutants of this species have been obtained by U-V irradiation for ultimate use in genetic studies. New isolates of *Ectocarpus,* isolated in Japan during the past summer, are being cultured for comparative studies.

Recent visiting scientists in Dr. Lewin's laboratory included Dr. V. Vivienne Cassie, University of Auckland, New Zealand, and Dr. Alasdair H. Neilson (now at the Karolinske Institute, Stockholm, Sweden). While he was at Scripps, Dr. Neilson collaborated in a study on the physiology of heterotrophy in a green flagellate, *Chlamydomonas dysosmos.* He showed that a mutant which is incapable of growth in darkness apparently lacks the ability to synthesize the adaptive enzyme iso-citrate lyase and is, therefore, unable to assimilate acetate as a substrate. This accounts for its inability to grow in darkness.

A new venture among Scripps scientists is the investigation of oceanic insects, a group of marine animals which before has been generally neglected. Dr. Lanna Cheng just published a full description of a recently described species, *Rheumatobates aestuarius,* from Baja California, and she is currently working on the zoogeography of "ocean striders" (Halobates spp.) from collections of neuston made in Californian waters of the Pacific, from the Indian Ocean, and from the Atlantic.

Dr. Richard H. Rosenblatt continued his studies of the fishes of the eastern Pacific. A study was completed on the fishes of the Gulf of Chiriqui, Panama. This region differs from the well-studied Gulf of Panama, in that there is little or no upwelling and concomitant drop in surface water temperatures during the dry season. The Gulf of Chiriqui supports abundant growth of coral, probably as a result of the year-round warm temperatures. Collections of fishes made at several localities within the Gulf revealed a fauna different from that of Panama Bay. Most notable is the presence of a number of species of Indo-West Pacific origin. Many of these species had been taken only from the oceanic islands of the eastern Pacific, but were supposedly absent from the mainland of the Americas. The occurrence of these forms in the coral-rich Gulf of Chiriqui indicates that they are transported to the mainland, but that their ability to establish populations is determined by local ecological conditions.

Tetsuo Matsui initiated a study of the life history and population dynamics of the macrurid fish *Coryphaenoides acrolepis.* The Macruridae is the most important family of the continental slopes. There are approximately 300 species, many of which reach a relatively large size and considerable abundance. Despite this, the life history pattern of the family is almost unknown. *C. acrolepis* is present in large numbers off California in depths ranging from 600–1,200 fathoms. It is consequently a favorable species to study in order to learn something about this important group of predatory fishes. A sampling program has been initiated, and the data are beginning to be analyzed.

Investigations of the biochemical changes which accompany adaptation to different temperatures are being continued in the laboratory of Dr. George Somero. The estuarine fish *Gillichthys mirabilis* is being used in a series of studies to determine whether marked changes in the qualitative composition of protein systems occurs during thermal adaptation. Currently, a detailed examination of the effects of temperature on rates of macromolecular synthesis and degradation, i.e., "protein turnover," is in progress. A major goal is to determine the amount of energy which must be expended to replace degraded macromolecules (proteins and nucleic acids) at different temperatures. The differences in function and structure which characterize enzymes from "cold-blooded" animals evolutionally adapted to different temperatures are also being studied.

Dr. Benjamin E. Volcani and his colleagues extended their investigations of the biochemistry and ultrastructure of the diatom wall to the transport of silicic acid and the role of silicon in regulation and synthesis of a variety of enzymes.

Dr. Farooq Azam developed a procedure for isolating newly forming ("embryonic") walls from synchronized cultures of *Navicula pelliculosa.* The procedure permits the fractionation of the embryonic walls according to size and hence the stage of development. The preparations were checked at different stages of development for the presence of enzymes (acid and alkaline phosphatases, ATPase, 6-glucuronidase, glucose-6-phosphate dehydrogenase, and arylsulfatase); only alkaline phosphatase activity was found. Chemical analyses of the embryonic walls are in progress.

Ultrastructural studies of the embryonic walls by Dr. Lawrence A. Dyck and Mary Lou Chiappino revealed an unusual structure in the region of the central nodule. It consisted of an array of columns situated at the interior and exterior faces of the shell. The columns gradually disappear as their interstitial spaces are filled in during maturation of the shell and are sealed when the wall has reached about half of its final size. The relation of this structure to the development of the cell wall is being studied.

On investigating the transport of silicic acid (using ^{31}Si) and germanic acid in the apochlorotic diatom *Nitzschia alba,* Dr. Azam and Dr. Barbara B. Hemmingsen found that silicic acid is transported by a carrier-mediated process; the system has a high affinity for the substrate ($K_t^t = 4 \times 10^{-6}M$), temperature dependent ($Q_{10} = 2.0$), and is sensitive to the inhibitors of energy production. They also demonstrated the presence of an extract-

able cytoplasmic silicic acid pool. The intracellular concentrations, higher than the extracellular concentrations, imply the operation of an active transport system. The implications of these findings to the physiology and biochemistry of cell wall synthethis and particularly to the processes of silicification are being investigated. Dr. Hemmingsen showed that silicic acid stimulates ATPase in membranes isolated from *N. alba.* The enzyme may be involved in silicate uptake by the cell.

Germanic acid, a specific inhibitor of diatom growth, was found to be actively transported by a number of diatoms. The transport system, studied in detail in *N. alba,* is a carrier-mediated, active-transport system leading to concentration gradients of the order of 1000x. Germanic acid also produces morphological aberrations in the cell walls of a number of diatoms *(N. pelliculosa, N. alba, N. angularis* and *C. fusiformis);* their ultrastructure nature is different in different diatoms.

Dr. Cornelius W. Sullivan studied the role of silicic acid in regulating DNA synthesis in synchronized cultures of *Cylindrotheca fusiformis.* He found that silicic acid is involved in the formation of DNA polymerase and thymidylate kinase. Experiments with inhibitors of protein synthesis demonstrated that *de novo* synthesis was required for the silicic acid effect on these enzymes.

The studies of Drs. Hemmingsen and Sullivan are of great significance, since they show that silicon, far from being biologically inactive as had always been thought, is essential for cellular processes other than shell formation. Such a requirement may prevail in other organisms.

In the laboratory of Dr. Claude E. ZoBell, the stability and hydrolytic reaction rates of some ecologically important microbial enzyme systems were determined under deep-sea environmental conditions. Agarases, cellulases, and chitinases were found to be stable and active at 100 atm at rates which depended upon temperature, pH, chemical composition of the medium, and the source and structure of the enzyme. Certain cellulases and chitinases were more active at 100 atm than at 1 atm in the neighborhood of 3°C. Magnesium and calcium ions were found to enhance the pressure tolerance of various microbial species and their enzymes. Collaborating in this research during the year were Dr. Juhee Kim, associate professor of microbiology, on sabbatical leave from California State College, Long Beach, and Dr. Robert E. Marquis, associate professor of microbiology, on sabbatical leave from the University of Rochester School of Medicine, Rochester, New York.

In other studies, carcinogenic hydrocarbons, including 3, 4-benzpyrene and several benzanthracenes, were shown to be synthesized by marine bacteria; other bacterial species slowly oxidize such hydrocarbons.

Ocean Research Division

Dr. Robert S. Arthur continued studies on the dynamics of physical phenomena in the nearshore and oceanic regions. Further attempts were made to assess the barotropic and topographic component in observations of variations in temperature and salinity. A fully satisfactory model has not yet been achieved. During a two-month visit by Dr. Kern E. Kenyon, University of Rhode Island, Kingston, a review was made of his extensions and additions to earlier work on wave refraction by currents.

Dr. Jeffrey L. Bada developed a method for the dating of deep-sea sediments and fossil bones based on the racemization reaction of amino acids. The amino acids contained in the proteins of living organisms are largely of the L-configuration. Therefore, the amino acids incorporated into sediments and bones are initially of this configuration. However, over long periods of time L-amino acids are slowly transformed into D-amino acids, and this process continues until the ratio of D/L becomes 1.0. The rate at which this reaction occurs has been investigated in detail. Therefore, by knowing the D/L ratio for any particular amino acid in a fossil or sediment, an age can be estimated. This method has been applied to the dating of cores from the North Atlantic and Caribbean and to bones obtained from various sites throughout the world.

During 1970–71, the technical and administrative staff of the GEOSECS Operations Group, under direction of Arnold E. Bainbridge, expanded from six persons to more than 40. These included engineers, electronic and marine technicians, computer programmers, staff research associates (analysts), and supporting skills, such as design illustrator, machinist, and secretary. This rapid staff build-up reflected the multiplicity of tasks to be accomplished by the time the Geochemical Ocean Sections Study expedition goes to sea in July, 1972.

Major achievements included the hiring and organizing of the operations staff for shipboard work; the planning, engineering, and coordination of the construction of shipboard samplings and analytical facilities; the training of sea-going technicians in the procedures of seawater analysis that will be used; the determination of logistic requirements for the expeditions; and personnel sea-time scheduling.

Plans call for GEOSECS scientists to measure several parameters. They are salinity; temperature; dissolved O_2; total CO_2; alkalinity; pH; Na; Ca; Mg; K; Fe; Ni; Cu; Zn; Ba; dissolved N_2, He, Ar, and Ne; dissolved organic carbon; reactive SiO_2, PO_4, and NO_3; C^{14}; Ra^{226}; Ra^{228}, Si^{32}, tritium; Sr^{90}; Cs^{137}; Rn^{222}; deuterium; O^{18}; C^{14}; He^3; particulate-matter concentration, mineral phases, and C^{14}, and atmospheric water vapor, pCO_2, N_2O, deuterium, O^{18}, and C^{13}. *In situ* measurements will be made of salinity, temperature, and dissolved oxygen as a function of depth, and the distribution of suspended material in the bottom few hundred meters will be measured using a laser nephelometer.

Staff electronic technicians and engineers fabricated computer interfacing equipment, and project programmers developed the necessary software to interface the two GEOSECS computers with these analytical systems: alkalinity (pH and CO_2), STD (salinity-temperature-depth), radon, autoAnalyzer (nutrients), gas chromatograph (total carbon and argon/nitrogen ratio) atmospheric parameters, oxygen, and nephelometer.

All data will be recorded in such a way that the station work can be replayed on shore at a later date, all data having been stored automatically in the shipboard computer. The computer has been programmed to correct thermometer readings; calculate peak areas from gas chromatographs; resolve AutoAnalyzer peaks; display salinity, temperature, and depth (STD) data in real time; control automatic titrations; determine salinity from conductivity measurements; determine surface, atmospheric, and deep water pCO_2 values; monitor radon counters; and calculate dissolved O_2 concentrations. In case of a breakdown in the automatic entry system, provisions have been made to enter data manually into the computer for all systems except STD. In the event the latter occurs, the STD readings will be recorded on punched tape. Within minutes of the measurement being made, the final value can be made available to the chief scientist, who will determine whether the sampling and analytical work have been satisfactorily carried out or whether more detailed sampling is to be made before the station is vacated.

A complex multiplexing and sequencing system was also developed. Some of the actual analytical instruments or systems were developed and/or fabricated by the technical staff. These include the alkalinity titrator radon counter and STD-O_2 (in conjunction with Woods Hole Oceanographic Institution). Two sea trials were held for actual testing at sea of the various systems, samplers, components, and personnel.

The research activities of the Radiocarbon and Tritium Laboratory under the direction of Dr. Hans E. Suess followed the same general paths as in previous years. The capacity of the laboratory was enlarged in that there are now more operating counters than in the past.

One aspect of radiocarbon investigations is the measurement by Dr. George S. Bien and graduate student Timothy W. Linick of C-14 in Pacific surface seawater samples. C-14 created by atmospheric nuclear weapons tests, bound as CO_2, has been exchanging with CO_2 previously present in the oceans. Latitudinal variations in surface seawater C-14 are due both to the location of the large tests (primarily in the northern hemisphere) and to ocean mixing processes; where colder, deeper, and relatively C-14-poor water mixes upward, the surface C-14 activity is low. Minima in C-14 activity are found near the equator and at far southern latitudes, maxima of approximately 20 percent above pre-bomb levels at mid-latitudes. Although C-14 levels in the northern hemisphere are still slightly higher than those in the southern, the C-14 levels worldwide appear to be leveling off.

When surface seawater data are combined with atmospheric and deeper seawater data, significant environmental mixing parameters can be calculated.

Another area involving radiocarbon measurements is associated with tree ring chronolgy. During the past year graduate student William F. Cain initiated and carried out studies by comparing C-14 activity of rural and urban tree rings of the same age. The objectives of this investigation are to establish whether C-14 activity can be used as an indicator of fossil fuel carbon dilution and the possibility that C-14 could be used as an index of pollution.

Tritium investigations by Karen O. Dockins and graduate student Robert L. Michel centered on vertical profiles taken on Styx, Scan, and Seven-Tow Expeditions. The main emphasis is on profiles taken in a north-south direction from Samoa to Hawaii to Adak. From these measurements it is apparent that the H^3 distribution in the areas north of the equator and south of Hawaii are controlled to a large extent by horizontal advection. The processes controlling tritium distributions south of the equator are less clearly known due to a scarcity of data and the nonsymmetrical fallout of tritium. The tritium distribution in the north central Pacific is largely dependent on vertical processes, but there is evidence of some significant horizontal processes at work here also.

Dr. Charles S. Cox and his group continued their work in obtaining high resolution vertical profiles of temperature in the ocean. These "microstructure" measurements are made from freely falling tubes which sense temperature fluctuations down to the millimeter scale and internally record the data on magnetic tape. A microscale conductivity probe was built as part of a PhD dissertation by Michael C. Gregg. With the temperature and conductivity data it has been possible to compute the vertical salinity and density profiles to a resolution of 2 cm. From microstructure observations made in the San Diego Trough, it has been possible to identify small overturning events. In addition, the numerous temperature inversions in this region were resolved into families of meter-thick layers separated by sharp interfaces which in some cases are less than 1 cm thick. The formation of this sharply layered structure has been attributed to the diffusive instability which occurs when warm, salty water underlies cooler, fresher water. Additionally, measurements were made off Cabo de San Lucas during the Fresnel cruise to study the strong temperature inversions in that region.

The data records are being analyzed by Peter W. Hacker as part of his dissertation research to determine the three-dimensional structure of temperature and the dissipation of temperature fluctuations. He has found the ocean to be well stratified for vertical length scales greater than 30 cm. Over smaller vertical length scales, patches of turbulent fluctuations are observed which tend to an isotropic structure with decreasing size. The temperature fluctuations were found to have a variation of intensity of about 300 to 1 over a typical data record.

Dr. Cox continued development of a mini-computer system which can be taken to sea to analyze data records on board following retrieval of the microstructure recorders. In conjunction with Bill P. Johnson, Dr. Cox built five new free-fall microstructure recorders which can be used to obtain vertical profiles from the surface to four kilometers as well as to study the horizontal extent of small scale features.

Dr. Tsaihwa J. Chow and his associates are studying the biogeochemistry of lead. They continued to monitor the atmospheric lead aerosols in the San Diego region during the past year. Sampling stations are located at the Scripps Pier, Mission Valley, downtown San Diego, and at nearby Mount Laguna. The 1970-71 annual average lead content in the San Diego urban air was 2.1 micrograms per cubic meter and that of the Scripps Pier was 0.44 microgram per cubic meter. The atmospheric lead content showed a seasonal cycle with a winter high and a summer low. High lead aerosol content was observed during the year when temperature inversions which trap pollutants in a limited air space occurred. Being above the inversion layer, the Mount Laguna air samples averaged 0.075 microgram of lead per cubic meter. By comparison with the previous data taken at the same site, the Mount Laguna lead aerosols showed an increasing trend.

Marine sediments of the Santa Barbara Basin were analyzed for their lead content. These sediments were taken with the box core technique developed by Andrew Soutar. With the box cores, separate successive annual deposits up to 200 layers can be identified to provide a record concerning the chemical constituents of the drained materials. Samples representing ten-year duration of sedimentation for the past century showed that the most recent marine deposits contain three to five times more lead than that of a century ago. This trend reflects an increase of lead in the material drained into the coastal ocean waters.

The lead content of several species of marine fishes was also determined. With the International Decade of Ocean Exploration baseline study, tuna fishes (yellowfin and skipjack) were dissected and their parts analyzed for lead contents.

Experiments were also carried out on sculpin *(Scorpaena guttata)* acclimated in water enriched with a lead solution. Specimens were taken at various time intervals within a three-month period to determine whether the fish would accumulate lead in its body. Results showed that excessive lead was first adsorbed by the fins, gills, and skins with scales. With the progress of time, excess lead showed up in the digestive tract and various internal organs.

Dr. Russ E. Davis is concerned with various aspects of surface waves and their generation by wind. Data from a multiple element wave array are being analyzed using recently developed techniques for estimating the directional energy spectrum. These data will provide high resolution wave spectra characterizing the distribution of wave energy in trade wind regions and in conditions of active wave generation. Further, these data, coupled with photographic records of the sea surface, are being used to study the breaking of waves in the deep ocean.

Measurements of the turbulent flow over the air/sea interface (made from FLIP) show that there are definite wave-induced perturbations of the turbulent components of the flow. This shows, as suggested in some of Davis' theoretical work, that wave induced fluctuations of turbulent Reynolds stresses play an important role in wave generation dynamics. Because of statistical uncertainty the exact nature of these stresses cannot be determined from the limited amount of data available now, but further measurements are planned.

Theoretical studies of the process of wave generation were completed. One study attempted to compare the predictions of a modified version of the theory developed by Dr. John W. Miles of UCSD to the laboratory experiments of flow over a wave made by Dr. Robert H. Stewart of Scripps. The primary result of

Dr. Michael C. Gregg and Jack C. Lucas launch Ocean Research Division microstructure recorder. Instrument records small-scale temperature and conductivity in vertical columns of seawater. Slow, uniform descent of recorder is accomplished when blades attached to instrument open at a pre-set depth. Upon return to surface, radio attached signals ship for retrieval.

this comparison was a demonstration of the importance of fluctuations of turbulent stresses. The particular model chosen to describe these stresses was only partially successful, although there was a definite improvement over predictions based on Dr. Miles's assumption that turbulent stress fluctuations are negligible. A second study examined various methods of predicting the wave's influence on the turbulence. Surprisingly, an eddy-viscosity model appeared most successful in describing the measurements of various workers.

Dr. Paul K. Dayton began a long-term experimental study of some of the mechanisms by which the structure of southern California kelp communities is maintained. Specifically, experimental manipulations were initiated which are designed to quantify the importance of (1) the factors determining the patterns of algal recruitment, (2) the algal-algal interactions, such as competition for light and substratum, (3) the algal-animal interactions, in particular the importance of grazing, and (4) the animal-animal or predator-prey interactions. Natural fluxes in the structure of the community are being monitored with an extensive series of permanent transects.

A sampling program designed to study the effect of enrichment from the San Diego sewer outfall on the population of the starfish *Patiria miniata* began. Because of its broad diet, an increase in the *Patiria* population could have a profound impact on the kelp community.

Additional work included the publication of a paper describing the formation of ice stalactites with lengths of 1.5-6.0 meters growing under the pack ice at McMurdo Sound, Antarctica. From the growth rates of these stalactites the volume flow of the brine was calculated to be in the order of 1 liter per minute. Two other brief papers dealt with the implications of pollution to the benthic community at McMurdo Sound. An additional paper was also prepared evaluating the roles of competition and disturbance in structuring an intertidal community.

Dr. Edward W. Fager and his colleagues continued their studies of the ecology of single species populations and communities. Recent work includes studies of the species structure of the benthic community around sewer outfalls before and after output through the sewer; the age structure and population dynamics of one of the most abundant vertically migrating small fish in the open ocean; the ecology of a "fugitive" species of barnacle; the interrelationship between internal waves and the nutrient and light experience of a phytoplankton community; the dynamics of a three-species system composed of an encrusting bryozoan and two nudibranch predators on it; the relation between the Radiolaria in the near surface waters and those found in the sediments below; the epifaunal community on a local species of gorgonian; and the development and dynamics of the community that forms on solid substrate placed in the midst of a sand environment. All of the studies combine field observation and experimentation with laboratory studies and computer simulation.

Some of the more interesting results of these studies are the observed development of a viable but not very diverse community around the sewer outfall after sewage starts through, replacing a more diverse one; the fact that the fugitive barnacle effectively uses the castoffs of human society (such as lost swim flippers, beer cans and Chianti bottles, and other solid waste on the bottom) and may thus be benefited by this pollution; the effects of period length of the internal waves that indicate that the usual process of taking samples at the same time every day only sees a very small part of the overall experience of the phtytoplankton; the considerable differences, especially in relative abundances, found between the Radiolaria seen in the water column and those that make it to the sediments; and the constancy of numbers of some animals, especially starfish, on the solid substrates in the sand despite the fact that there is a continuous immigration and emigration of individuals. The work has emphasized the concept that community dynamics are the result of an interweaving of repeated, and thus predictable, phenomena with those that appear to have no pattern and thus must at least for the moment, be classed as random. All of the studies on the computer that have been even moderately successful in modeling the observed events have had a prominent random component in them.

Continuing a search for useful pharmaceuticals from marine sources, Dr. D. John Faulkner and his colleagues isolated several antibiotics from sponges and observed the first instance of antibiotic activity in a tunicate. Their research on the toxins from several species of starfish revealed that each starfish contains a complex mixture of saponins of varying toxicity. Studies of the chemical sex attractant used by mysid shrimp and the chemical defense mechanisms used by the sea hare were initiated.

In completing his thesis research, Michael R. Petersen performed the first synthesis of optically active juvenile hormone of known absolute configuration. Samples of the synthetic juvenile hormone have now been used to determine the amount of juvenile hormone in a single insect and to determine the effect of juvenile hormone, a potential insecticide, on crustaceans. The chemical identity of a compound having juvenile hormone activity, which was obtained from the lobster, *Panulirus interruptus,* is under investigation.

Dr. Jean H. Filloux collected tide data at 16 stations in the Gulf of California to be used for comparison with mathematical tide prediction models of Drs. Nichols Grijalva and Myrl C. Hendershott.

From the comparison, the investigators hope to find the correct form of frictional influence on the tidal motion as well as to provide input to the geophysical problems involving tidal loading and distortion of the crust beneath the Gulf.

The shoaling northern part of the Gulf where important bottom friction is expected to occur was densely sampled. Adequate coverage of the southern coast of Baja California and of the coast of Sinaloa was also achieved. However, survey of the complex, hardly accessible, yet greatly significant area around Angel de la Guardia and Tiburon Islands had to be temporarily postponed.

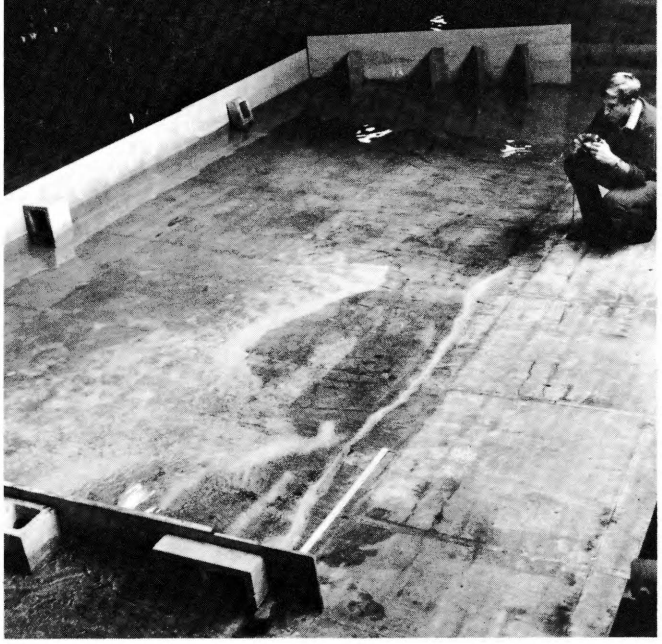
Measurements of the electric and magnetic fields under the sea are planned as part of the Mid-Ocean Dynamic Experiment to be run in the Sargasso Sea. The aim of MODE is to identify the importance of the fluctuating motions with scales on the order of 100 mm in the motions of the sea. The electromagnetic measurements will contribute to this end by providing integrated measures of the ocean motions. They will also supply information on the electrical conductivity of the oceanic lithosphere.

In this group of workers, attention is currently directed toward measuring the level of electric field "noise" caused by small scale oceanic motions and electrochemical problems.

Dr. Theodore R. Folsom continued a study of distribution of natural cesium that is present in the ocean in only very small amounts and which is spread so uniformly that specialized analytical techniques are required before anomalies can be demonstrated and followed. Highly purified reagents and special flame photometers are being developed for study of seawater concentrations as are neutron activation procedures for studying traces of cesium in marine organisms.

Traces of radioactive cesium (Cs^{137}) that entered the ocean as nuclear fallout have been found to persist for years in the upper layers of the ocean by comparing 1964 and 1971 concentrations. Observations of changes in radioactive cesium concentrations in albacore tissues between 1964 and 1971 have emphasized the long residence time of biologically passive materials in the upper layers of the Northern Pacific. On the other hand, observed changes in concentrations of heavy metallic constituents of nuclear fallout in tissues of albacore over similar periods suggest that many trace elements are strongly redistributed by biological agencies in the upper layers and suggest that predators obtain heavy metals largely from concentrations accumulated by their food organisms.

Dr. Vernon E. Hodge, in collaboration with Dr. Folsom, Dr. David R. Young, and Kai Wong, is comparing the behavior of several metallic trace elements in the marine biosphere through measurements of concentrations of their radionuclides that have entered the ocean as fallout or from reactor wastes. Comparisons of radioactive concentrations measured in the livers of a well-known albacore population of the North Pacific over seven years have suggested how long such trace metals as cobalt, manganese, zinc, and silver have been maintained available to predators in the upper layers of the Pacific. Zinc-65 concentrations remained almost constant in this albacore population between 1964 and 1971 suggesting that repeated inputs to the ocean of this fallout constituent must have been made. Highest concentrations of Co^{60}, Ag^{110m}, Ag^{108m}, and Zn^{65} were found in the larger, older fish individuals; these generally have been caught in central oceanic



Dr. Anthony J. Bowen, Sea Grant visiting scientist working with Dr. Douglas L. Inman of the Ocean Research Division, studies crescentic bars created by standing edge waves in the Scripps Hydraulics Laboratory wave basin.

regions far from coastal pollutions. Special procedures for determining other small traces of Ag^{108m} (127 yr half-life) were developed last year.

Small environmental changes in cobalt and silver nuclides attributable to the first power reactor in Southern California were demonstrated through measurements made in molluscs and algae. Some preliminary measurements of the alpha emitter, Pu^{239}, in aglae emphasized how selectively algae behave toward heavy metals; they also suggest how important it is to sample only appropriate species and also how important it is to analyze only carefully chosen organs. Local concentrations may vary 100- or even 1000-fold within a given organism.

In the research group of Dr. Joris M. Gieskes, graduate student Edward R. Sholkovitz carried out further investigations on the physical-chemical characteristics of the Santa Barbara Basin. The interstitial water chemistry of the anaerobic varied sediments of this basin were also investigated with the aim of establishing diagenetic changes in rapidly depositing reducing sediments.

In December, 1970, and January, 1971, Dr. Gieskes took part in the special geochemical leg (Leg XV) of the Deep Sea Drilling Project in the Caribbean Sea. He carried out shipboard analysis for pH and alkalinity and further analyzed the samples at Scripps for calcium, magnesium, ammonia, and phosphate. He also participated in July, 1971, in a cruise of the German R/V *Meteor*. An array of five stations was laid across the North Atlantic Ocean to complement the upcoming north-south section involving Woods Hole Oceanographic Institution's R/V *Knorr* in the GEOSECS program.

With graduate student Peter Christensen further studies were carried out of the activity coefficients of mixed electrolytes. Theoretical studies indicate that well on the way is a predictive theory for activity coefficients in geologically important systems.

Dr. Hendershott and Dr. Paola M. Rizzoli, a visitor at Scripps from Laboratorio Dinamica delle Grande Masse, Venice, Italy (a laboratory studying oceanographic problems connected with the periodic flooding of Venice), analyzed hydrographic data taken in the Adriatic Sea during the winter of 1965-66 and found an apparent correlation between the appearance of dense water in the shallow Northern Adriatic Sea and the occurrence of anomalous winds bringing cold, dry air masses from northern continental Europe. The flow which results when this dense water is formed may be an important part of the prevailing winter current system in the Adriatic Sea; a winter cruise is planned for January-February, 1972 to document the formation process and the associated flow in detail.

Dr. Hendershott and graduate student David W. Behringer examined hydrographic data from the southern central Atlantic and the California Current for evidence of the conservation of potential vorticity along streamlines of flow. They tentatively conclude that potential vorticity could be used as a tracer of large scale flows, although existing grids of hydrographic data are too widely spaced in space and time for its optimum utilization.

The Shore Processes Research Group of Dr. Douglas L. Inman is actively studying the complex interaction phenomena prevalent in the nearshore environment. The program includes field measurements of waves, currents, and sediment transport as well as laboratory experiments utilizing the facilities of the Scripps Hydraulics Laboratory.

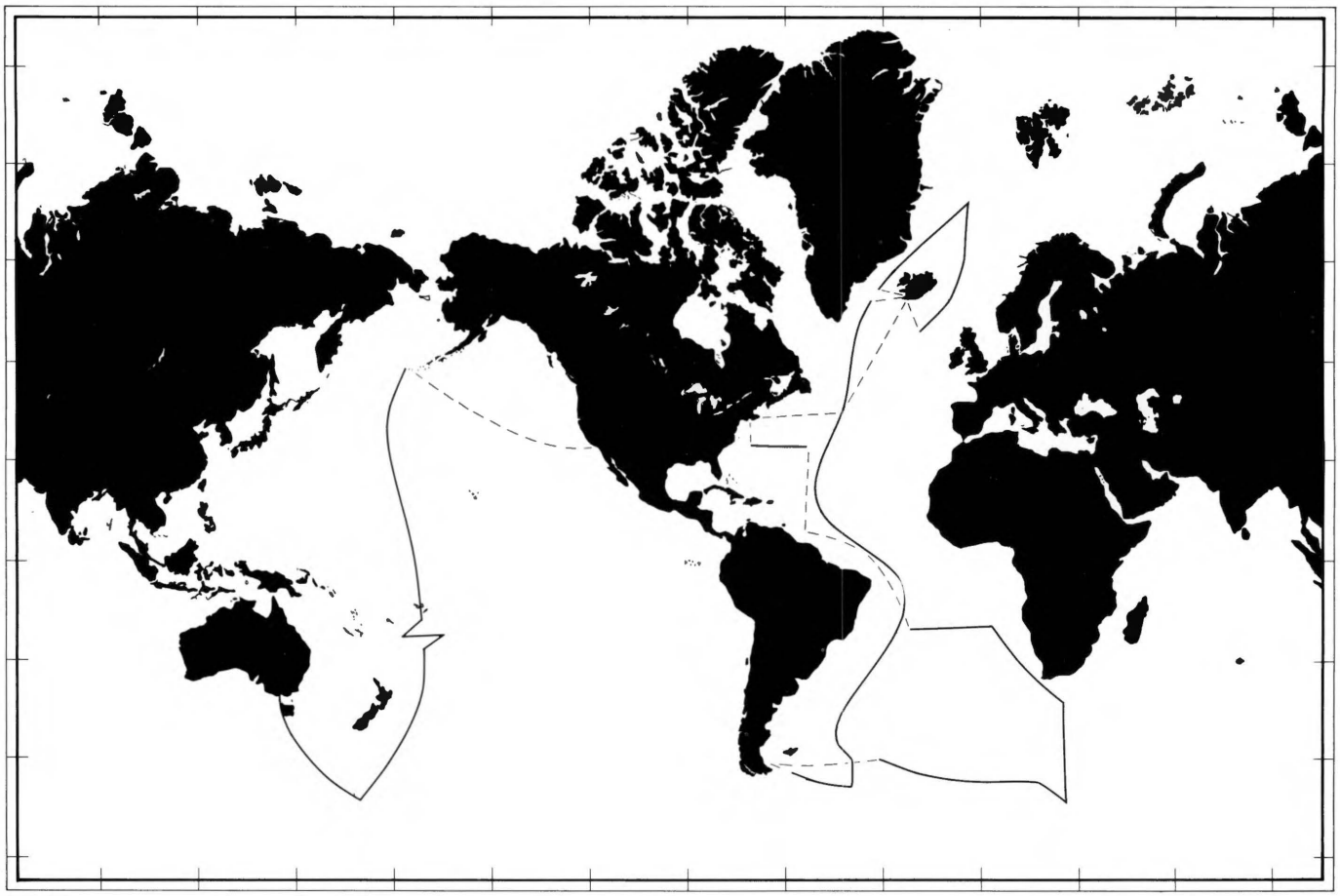
Research accomplishments during the last year included study of the velocity fields associated with edge waves on a sloping beach. Standing edge waves were found to provide an explanation for the formation of crescentic bars in regions of small tidal range. Dr. Anthony J. Bowen, visiting scientist from the Institute of Coastal Oceanography and Tides in Birkenhead, Cheshire, England, verified in laboratory experiments that crescentic bars are caused by standing edge waves. Drs. Inman and Bowen have also concluded an associated study of the selective trapping of edge wave modes by irregularities in the coastal topography. Trapping of edge waves by topographic irregularities in the coastline will possibly explain other phenomena such as anomalous currents in submarine canyons and long period waves in the nearshore zone.

Other accomplishments included successful laboratory experimentation with phase-dependent roughness elements for controlling the direction of sand transport by waves. These roughness elements resemble natural asymmetrical sand ripples and influence the sand transport because an intense vortex forms in the lee of the steep face. This vortex traps and suspends sand, which is lifted above the roughness element and carried in a new direction when the orbital water motion reverses its phase. Thus, the direction of sand transport is dependent upon the relation between the steep face of the roughness element and the phase of the orbital velocity-net transport being in the direction of the orbital velocity that is out-of-phase with the maximum vortex formation.

In order to more fully observe the broad tapestry of energy translation which occurs as a result of wave power incident upon a coastline, a nontraditional approach became attractive to avoid the limitations of looking through small windows at many different times. The simultaneous acquisition of dependable synoptic data from the waters over the continental shelf led to the design of the shelf and shore simultaneous system (SASS) by this research group. This system consists of 1) up to six deployed shelf stations, which are bottom referencing spar buoys containing various sensors and a Radio Frequency (RF) telemetry transmitter and, 2) a vehicle-mounted movable shore station which receives the RF signals and interfaces them to data recorders. Sampling of the sensors is accomplished at an 8,000 sample per second rate. This high sampling rate insures less than one degree of phase error (e.g., for a 3 Hz signal) between any two of the fifteen data sensor channels available to each shelf station. Thus, the data may be treated as though obtained simultaneously rather than sequentially.

The shore station acquires data via a pulse code modulated RF telemetry system. The sensors most commonly used on the shelf station will be digital wavestaffs, pressure sensors, and current meters of the newer two-component electromagnetic type. Thus, each shelf station will comprehensively monitor the physical environment at its particular site, and arrays of shelf stations will acquire data from larger shelf areas. Other specialized sensors are being developed for use with the shelf station. A prototype high resolution sonar for recording the ripple geometry at the water-sediment interface is being tested for use in the observation and recording of sand ripple changes in response to different wave regimes.

Another new sensor under development is a suspended sediment monitor for use in the evaluation of the suspended sediment load in the littoral environment. This sensor uses optical backscatter from the suspended sediment for light wavelength greater than 7000A. Two photo diode detectors are used to determine the light arriving from the source—one detects light directly from



Geochemical Ocean Section Study (GEOSECS), established in March, 1971, as part of the National Science Foundation's International Decade of Ocean Exploration, will sample waters of the Pacific and Atlantic Oceans. Woods Hole's R/V Knorr *operates in the Atlantic in 1972–73, and Scripps's R/V* Melville *works in the Pacific in 1973–74.*

the source, the second receives light which has been scattered. The ratio of the two detector signals is related mathematically to the scattering coefficient of the medium around the meter. This scattering coefficient is proportional to the concentration of the suspended sediment.

Joseph N. Suhayda recently completed a PhD dissertation analyzing the effects of bottom slope on shoaling waves. Measurements of wave height outside and inside of the break point and measurements of bores and run-up in the surf zone were made on two natural beaches to determine the characteristics of shoaling and breaking waves. It appears that measured changes which occur in the nearshore wave spectrum are in agreement with a theoretical model derived from the linear shallow water or long wave equations. The solutions of the equations for a plane sloping bottom boundary consist of zero order Bessel functions which were matched across slope changes in order to model the natural beaches. The theoretical model, in terms of the boundary conditions on the two natural beaches, appears to provide a basis for calculating wave reflection coefficients.

In the past year Dr. Robert L. Parker's main interest was to apply the recent discoveries of Drs. George G. Backus and J. Freeman Gilbert to geomagnetic problems. The first study undertaken was concerned with determining the electrical conductivity deep within the Earth from measurements of the slow variations of the geomagnetic field. The Backus-Gilbert theory is designed to evaluate the reliability of the final result, which the previous work could not do as well.

It was shown that the conductivity rises rapidly in the first 600 km to a value of about 1 Ω^{-1} m^{-1} (about one-fourth the conductivity of seawater), which agreed with earlier work. But Dr. Parker's work indicated that at present there is no certainty that the conductivity levels off in this region as was formerly supposed, because the uncertainties are too great. Electrical conductivity is the primary property used to infer temperature within the Earth, so an accurate knowledge of conductivity is of quite general interest.

A second problem to which the ideas of Drs. Backus and Gilbert were applied is that of finding the direction of magnetization of seamounts. These extinct submarine volcanoes are often magnetized, and it is possible to measure their small magnetic fields from ships and hence calculate their direction of magnetization. By assuming the ancient magnetic field resembles today's in its gross properties, one can estimate the motion of the seamount since its formation from this direction. Work is still in progress on this topic, but it appears that a more meaningful estimate of the direction will be found by this method than by previous techniques.

Another somewhat different project was the analysis of MPL's deep-tow magnetic data, in cooperation with graduate student Kim D. Klitgord. A numerical procedure was developed which allows reduction of the magnetic field observations to a level surface. These data are normally obtained on the uneven path of the deep-tow magnetometer, and this irregular surface results in confusion when one is attempting to correlate neighboring pro-

files. The theory of conformal mapping by analytic functions of a complex variable was used, and although the mathematics is more intricate than is usual for such simple problems, the computer implementation proved remarkably effective. Klitgord is planning to reduce a great quantity of data with the Scripps program and thereby to discover on how small a scale the observed magnetic lineations reflect global geomagnetic signals.

During the past year, Margaret K. Robinson's Bathythermograph Analysis and Processing Group prepared charts for an interim *Atlas of Monthly Mean Sea Surface and Subsurface Temperature and Depth of the Top of the Thermocline, North Pacific Ocean,* which was published by the Fleet Numerical Weather Central (FNWC), Monterey, California (May, 1971). The surface charts cover temperatures at levels of from 100 to 400 feet. This interim atlas with temperatures in degrees Fahrenheit has been issued to government and oceanographic institutions, pending final publicaiton in degrees Celsius and in color by the U. S. Naval Oceanographic Office (NAVOCEANO). A similar interim atlas of the Atlantic Ocean and adjacent seas is being prepared; the final publication is also to be published by NAVOCEANO.

These atlases are based on digitized bathythermograph (BT) temperature data collected since 1941. The analysis is being done by computer, using programs that are operational at Scripps and at FNWC. These computer programs, which produce complete fields from existing data by interpolation, also have been used to derive annual temperature distribution from 400-foot (125-meter) depths to the ocean bottom, as well as to determine annual salinity distribution (surface to ocean bottom) from the National Oceanographic Data Center (NODC) magnetic tape file of hydrographic station data. The numerical fields are checked for oceanographic consistency and then plotted, using contouring programs developed to run on the Scripps Cal-Comp plotter and the FNWC Varian plotter. The combined shallow and deep temperature and salinity values will be used in ocean model studies and to compute monthly dynamic topographies, heat budgets, and sound velocity fields. The numerical values will be retained on magnetic tape for updating and revision.

For the past three years, the group has contracted with NODC and NAVOCEANO to digitize BT temperature-depth traces. To date, the group has digitized 109,000 BT observations, using the BT digitizer designed and developed at Scripps under the sponsorship of the Office of Naval Research. Also, the group has digitized BT data received from Australia, Canada, Chile, Peru, the Netherlands, New Zealand, and Turkey, in addition to that from Duke University, Durham, North Carolina; Oregon State University, Corvallis; University of Miami, Coral Gables, Florida; and the University of Washington, Seattle.

In the past year, Dr. William G. Van Dorn and graduate student Kin Tsang conducted comprehensive laboratory and field investigations of the velocity and momentum fields within the breaker zone which is formed by a succession of waves approaching a sloping shoreline. They are concerned not only with the motions within individual waves, but also with the mean surging motions that result from their interactions. This study is basic to the mechanics of sediment transport, as well as to the engineering design of any structures intended to function within, or to withstand the effects of breaking waves in shallow water.

Because there is no adequate theory that describes motions in this regime nor any previous study that provides a basis for such a theory, a second objective is to describe these fields in useful parametric form and to attempt to advance the theory of wave behavior by an explanation of them. The study is divided into two phases: a laboratory study of trains of periodic waves breaking on uniformly sloping beaches and a field phase during which similar measurements will be conducted in the ocean. The laboratory phase is now complete, and it is hoped the field investigation will be finished within the near future.

Dr. Van Dorn is also writing a book, *Oceanography and Seamanship for Mariners,* under contract with Dodd Mead publishers in New York.

Dr. Bruce A. Taft carried out research on two legs of Aires Expedition. In cooperation with scientists from Harvard University and Woods Hole Oceanographic Institution, measurements of the velocity were made at the equator in the Pacific south of Hawaii. Moorings with current meters were placed on and near the equator. These measurements are now being analyzed to determine the characteristics of the time-dependent motion at the equator. Measurements of the temperature and salinity distribution were made around Jarvis Island which lies in the Pacific Equatorial Undercurrent, to determine the effect of the island on the flow of the Undercurrent.

The Kuroshio Current south of Japan has been shown to occupy two stable positions: one on the continental slope in relatively shallow water, and another in deep water—roughly 200 km south of the slope. In order to test a dynamical hypothesis about the underlying mechanism responsible for the maintenance of the two stable patterns of flow which was developed by Dr. Taft and Dr. Allan R. Robinson of Harvard, determinations of the path of the Kuroshio south of Japan were made. Hydrographic sections across the current and velocity measurements underneath the Kuroshio were obtained and are being analyzed, in conjunction with the path measurements, to determine the mechanisms of path control in the Kuroshio.

In cooperation with Andrew Bakun and Douglas R. McLain of the National Marine Fisheries Service, Monterey, California, Dr. Warren S. Wooster initiated a climatological study of upwelling on the eastern side of the Atlantic, between Cape Finisterre (43° N) and the Cape of Good Hope (35° S). The study is based on measurements of temperature, wind, and ship drift collected by merchant vessels during the past century. For coastal one-degree squares, long-term averages of sea surface temperature, wind stress, and offshore Ekman transport were computed. These and year-to-year changes in the same quantities are being examined for evidence of the linkage between the atmospheric circulation and the incidence of coastal upwelling.

With Dr. Mattahis Tomczak of the Institute für Meereskunde, Kiel, West Germany, Dr. Wooster is studying an intermittent upwelling observed from the German R/V *Meteor* off the coast of Mauretania in early 1970. Of particular interest is the evidence for along-shore filaments of high-salinity water, somewhat analogous to those previously observed off Baja California.

Marine Physical Laboratory

Research conducted by the Marine Physical Laboratory (MPL) includes a broad spectrum of projects, ranging from ocean studies utilizing the MPL-developed Deep Tow vehicle to the development of advanced underwater acoustic signal processor systems. The few research highlights presented here are representative of the work described in nearly 100 reports and studies produced by Marine Physical Laboratory staff members during the year.

The Marine Physical Laboratory was represented on two major expeditions—Seven-Tow and Antipode. Deep Tow was used on four legs of Seven-Tow Expedition involving R/V *Thomas Washington.* The first two were described in the SIO 1970 *Annual Report,* while the latter two are covered here.

During August, 1970, Drs. Fred N. Spiess and John D. Mudie conducted a set of detailed, near-bottom studies in the Aleutian Trench. Simultaneous side-looking sonar, precision bathymetry, seismic reflection, and magnetometer observations were made at a depth of 7300 meters near the floor of the trench and on both the outer and the inner wall. The observations confirmed the extreme smoothness of the trench floor with undisturbed turbidite layers extending up to within 500 meters of the inner trench wall. In addition to the trench survey, two long, near-bottom magnetometer profiles were made at latitudes 48°N and 49°N near longitude 140°W in joint investigation with Dr. Bruce P. Luyendyk of Woods Hole Oceanographic Institution. Near-bottom operations were also conducted over the Monterey Fan and selected areas of the continental margin of the United States as joint efforts with Dr. William R. Normark of Minnesota and Dr. Eli A. Silver of United States Geological Survey, respectively.

During testing operations of Deep Tow in San Diego waters, significant improvements were made in the art of free device navigation through the use of relay transponders, an extension of the precision near-bottom navigation system currently used by Deep Tow. In addition, a very high resolution modular aperture-side-scanning sonar was tested successfully. A promising study by William D. Ivers on the subject of the dynamics of long-towed cables has been undertaken, and it appears feasible to accurately predict the motion of a towed device given parameters of the towed device, cable, and motion of towing ship.

Dr. Theodore D. Foster investigated the stability of seawater in deep-ocean basins during Antipode Expedition in his continuing studies of convective phenomena. A theoretical convective model for the diurnal cycle in the upper ocean was developed which appears to agree well with the limited data available. Also carried out were theoretical analyses of haline convection induced at the freezing of seawater in a turbulent ocean and of the cabbeling instability resulting from the nonlinearity of the equation of state of seawater. Both processes may be important in the formation of Antarctic bottom water. A theoretical study was also made of thermohaline convection induced by the evaporation of seawater. Laboratory experiments on evaporation confirmed the theoretical predictions.

Drs. George G. Shor and Russell W. Raitt conducted seismic refraction observations devoted primarily to a study of the variation of velocity of elastic waves with the horizontal direction of propagation. Significant anisotropy of velocity of the uppermost mantle immediately below the Mohorovicic discontinuity has been observed in the eastern Pacific where it was found that the maximum velocity is in the direction of the transformed faults and normal to magnetic lineation. Studies to test this correlation were made on Antipode Expedition at two stations east of Japan and two stations in the northeastern Indian Ocean. The experimental techniques for carrying out these observations involve using only a single ship and deep-ocean moored sonobuoys. Anisotropy was observed at each of these stations, the direction of maximum velocity being roughly normal to the magnetic lineation.

Seismic refraction studies were made on Antipode Expedition as part of a study of the sedimentary deposits of the Bengal Fan by Drs. Joseph R. Curray and David G. Moore, the latter of the Naval Undersea Research and Development Center, at San Diego. Sediment thicknesses were determined where conventional reflection profiling was unable to achieve penetration to the bottom of the sediments. Sediment thicknesses up to 16 km were observed, showing this to be very probably the greatest sediment accumulation anywhere in the deep sea. On the final Samoa-to-San Diego leg of the Antipode Expedition, special studies were conducted utilizing expendable sonobuoys to obtain wide-angle reflection observations of sedimentary layers. This technique enables sedimentary velocities to be determined in transit, thus providing a very useful tool in underway studies of sea-bottom structure.

Prof. Victor Vacquier and Dr. John G. Sclater conducted geomagnetic studies of the Indian Ocean and northwestern Pacific. The magnetic work concerned a plate tectonic reconstruction of the Indian Ocean with some attention given to the old lineated magnetic anomalies east of the Ninetyeast Ridge observed during Antipode Expedition. The magnetic work in the northwestern Pacific involved bathymetry and dredging as well as magnetic surveys of seven seamounts to determine their past position and age. Heat-flow measurements were made in the Philippine Sea and the northwestern Pacific.

Drs. Spiess and Carl D. Lowenstein utilized deeply towed instruments for a survey of a deep-water dump area off the coast of the State of Washington. Side-looking sonar was used to locate the wreckage sites of five munitions-laden ships which had been detonated in the process of munitions disposal. The Deep Tow position and search patterns were referenced to a network of acoustic transponders planted in the area of sea bottom to be searched. The geographical positions of the transponders were in turn determined by correlating the towing vessel's position as fixed by satellite navigation with the relative positions of the transponders. The expedition succeeded in locating the wreckage of the five ships despite the extreme extent to which the ships' hulls were pulverized; few large pieces were found. The side-looking sonar pattern delineation was most effective and was supplemented by conventional stereophotography.

FLIP continues to prove its value as a Floating Instrument Platform and during the current year established an on-station record of 35 days. Throughout the nine years FLIP has operated for MPL, a total of 80 expeditions had been completed.

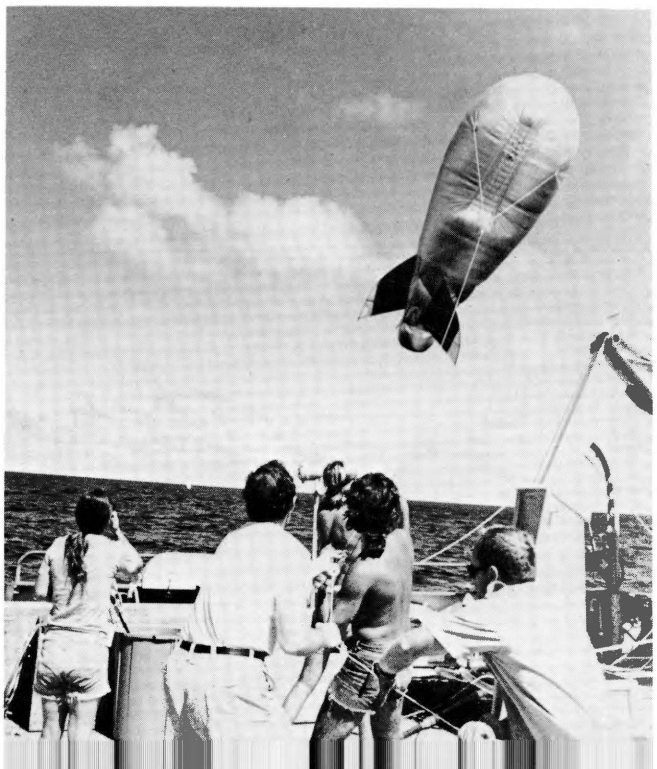
Dr. Philip Rudnick recently completed an analysis of storm conditions encountered by FLIP while in Hawaiian waters, based in large measure on motion pictures taken by Ray W. Hasse of the U. S. Navy Underwater Sound Laboratory. Dr. Rudnick and Hasse are joint authors of the resulting report, "Extreme Pacific Waves, December, 1969," (*JGR*, January 20, 1971).

The extreme maximum wave height (trough-to-crest) was about 25 m; predominant periods were 16 to 20 sec. The photographs revealed no substantial vertical motion of FLIP, in accord with calculations. However, reported inclinations of the order of 20° did not agree with the maximum value 2° calculated for the pitch-role angle. This suggests a major influence of drag forces which have not been considered in the calculated response ratios.

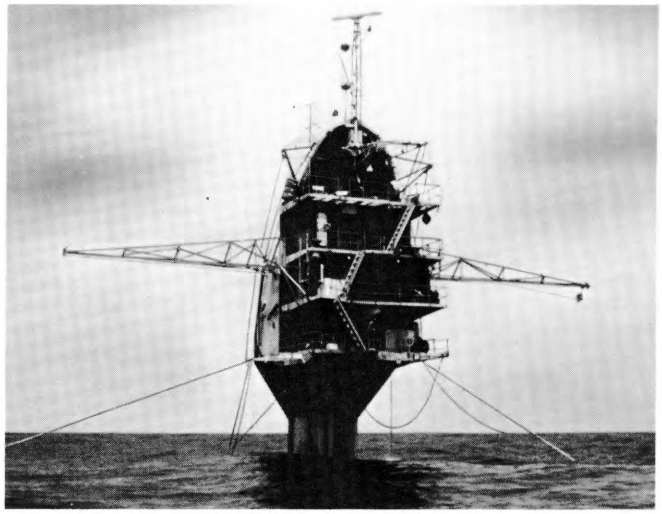
FLIP was utilized in April, 1971, in the test of a three-point deep ocean anchorage conducted by Earl D. Bronson, coordinated with acoustic and ocean current measurements being conducted by William Whitney. The three-point moor was conducted in 2,250 fathoms (4100 m) using sacrificial bottom tackle attached to simple shear pin assemblies, thence to neutral buoyancy line (5900 m for each leg). Upon completion of dropping ground tackle in 120° angular displacement, an aggregate leg tension of 7,000 pounds (3200 kg) at a scope of 1-½-1 resulted, requiring no further post-tensioning. The average excursion during the five weeks on station was 250 m. Wind and current observations indicated forces to be predominately due to current. The worst conditions experienced were a .3 knot (.15 m/sec.) current and 20 knot (10 m/sec.) wind emanating from the same quadrant producing an aggregate tension of 15,000 pounds (6800 kg) developed in the upcurrent legs. This is the first instance in which a stable platform has been three-point moored in the deep ocean. The acoustic observations made with FLIP in the moor included studies of depth dependence of ocean background noise and sound propagation studies.

RUM (Remote Underwater Manipulator) was utilized in sea-floor work conducted by Daniel K. Gibson on the floor of the La Jolla Canyon in water depths of 370 m to 420 m. Numerous core samples of canyon floor sediment were obtained and *in situ* measurements of sediment properties were made. At present, the most serious problems encountered in operating RUM effectively are those of visibility and visual ranging provided for the remote operator. A combination of high turbidity and monocular vision has proven to be a serious handicap in the efficient operation and positioning of the manipulator. Improvements in instrumentation to overcome these difficulties are being programmed for RUM. Research is being conducted in the area of acoustic imaging to provide the operator visual and range perception under extremely turbid conditions. Consideration is also being given to computer

After launching, Marine Physical Laboratory balloon will anchor to the deep sea floor. It carries radio transmitter to relay underwater acoustic signals to research vessel at ranges of 50 miles or more. —Alan C. Jones



Deck load of mooring line and scrap anchor chain are ready to implant three-point deep-ocean mooring for FLIP. Marine Physical Laboratory's Floating Instrument Platform was the first stable platform to be three-point moored in the deep ocean.
—Marine Physical Laboratory



FLIP is three-point moored in 4100 meters of water allowing scientists to conduct deep-sea underwater acoustic observations and ocean current measurements. Station was maintained 35 days.
—Marine Physical Laboratory

controlled basic operations, such as core sample executions and deployment and stowing of such instruments as the vane shear meter and cone penetrometer. Additionally, the increased telemetry requirements of new instrumentation will require computer control of telemetered data. In spite of the increased complexity, there are many inherent advantages in an unmanned, cable-tethered, mobile, sea-floor vehicle for the performance of many sea-floor tasks. Its feasibility and capabilities are now well established.

The Laboratory's underwater acoustics program directed by Dr. Victor C. Anderson continues to advance "the state of the art" of acoustic signal processors. Current projects include the final testing and installation of DIMUS (Digital Multibeam Sonar) aboard *Dolphin,* U. S. Navy research submarine, in preparation for extensive at-sea test and evaluation. The DIMUS concept utilizes clipped signal input instead of analog input; this type of signal (known to suffer negligible degradation of information in this context) is easily processed using digital techniques. Digital processing allows beamforming and beamsteering to be accomplished readily while compatible with nearly any sonar array configuration. Changes in array configuration require only that new element coordinates be programmed into the processor computer. Background noise measurements were conducted from the research platform FLIP using a 31-element array. Data were obtained consisting of sampled sequences of the detected beam outputs of the DIMUS beamformer. The data obtained have been recorded and processed with an FFT computer program to yield fluctuation power spectra along both the time coordinate and the bearing coordinate. The spatial spectra indicate that the sources of fluctuation are discrete point sources that have a spectral slope smaller than that of the Knudsen curves. The temporal envelope spectra have shown a strong negative frequency slope in the region of 0.01 to 10 Hz, at variance with the commonly accepted Gaussian model.

A 48-element, 256-beam, 25 kHz sample rate programmable DIMUS processor is currently being constructed to work with a variety of arrays on the research platform FLIP. The design approach used on the new DIMUS eliminates the need for a hard-wired steering matrix. The processor can thus be easily reprogrammed for different array configurations or for changes in the set of beam steering directions.

Dr. Robert A. Rasmussen has initiated studies of target detection in sonar displays. The need for data concerning the effects of target dimensions, viewing distance, signal continuity, target presentation time, and several other display parameters on detection performance became obvious during the development of the *Dolphin*-DIMUS displays. It is anticipated that results of the experiments being conducted will yield guidelines for the design of more effective sonar displays and a better understanding of the human observer functions in the sonar detection process.

DICANNE (Digital Interference Cancelling Adaptive Null Network Equipment) is a signal processor system also under development at MPL. DICANNE is a real-time digital processor designed to reject plane-wave interference from an operator selected direction prior to normal beam forming. Current work involves the design and construction of DICANNE II, an improved version of the original DICANNE system. One of the principal improvements incorporated in DICANNE II will be parallel channel processing as opposed to serial processing used in the original DICANNE; the latter proved to have serious limitations.

Studies are being conducted on the feasibility of expanding DIMUS and DICANNE to a large operational system consisting of several hundred elements. A system of this magnitude would extend capabilities for environmental acoustic studies many fold.

Physiological Research Laboratory

The Physiological Research Laboratory (PRL) has for some years devoted about half of its research effort to investigation of the biophysics of oxygen, water, and carbon dioxide transport in plants and animals. A major part of its effort has been directed toward demonstrating the underlying relationships regulating these processes in selected and sometimes unique biological systems.

The logistic capabilities of the Laboratory for fielding capable research expeditions has allowed its scientists to use the most sophisticated of methodology on the most dramatic and specialized biological examples of the principle to be investigated. The interest in water transport in plants, oxygen transport in animals, thermoregulation, and the effects of temperature and pressure on these parameters provided sound theoretical bases for the 1971 field programs in Antarctica.

Dr. Arthur L. DeVries joined PRL in January. He and his colleagues, Dr. Yuan Lin, postdoctoral fellow from the National Institutes of Health, Bethesda, Maryland, and John Duman, marine biology graduate student, are investigating the nature of freezing resistance and avoidance in poikilotherm fishes. The chemical structure and mode of action of unique glycoproteins

responsible for freezing resistance in polar fishes is under investigation.

The primary goal of research in Dr. Robert W. Elsner's laboratory is the elucidation of natural mechanisms of resistance to diving asphyxia. Considerable use has been made of comparative studies employing marine mammals as models in which the essential physiological mechanisms of asphyxial response can be conveniently examined. Some species of seals are capable of very long breath-hold diving durations. Their diving ability has been found to depend on greater than ordinary blood oxygen storage and the conservation of that oxygen by its restricted circulatory distribution to vital organs, brain and heart, which have a nearly continuous demand for oxygen. The cardiovascular changes are profound. Heart rate and cardiac output fall precipitously, sometimes to ten percent of the non-diving rate. Blood flow to organs of high anaerobic capacity (kidney, mesentery, and muscle) virtually ceases.

Studies by Daniel H. Kerem revealed specific cerebral tolerance by some seals to very low oxygen, and Kerem rcently completed his PhD thesis on this particular finding. From the diving mammal model, studies have been extended to asphyxia in terrestrial animals, adult and fetal. Earlier studies demonstrated that human subjects, laboratory dogs, and fetal sheep experienced bradycardia and peripheral vasoconstriction during apneic diving or acute asphyxia.

In conjunction with Dr. Fred N. White, UCLA School of Medicine, a histological investigation of arterial innervation in harbor seals has begun. Studies by blood flowmeter and X-ray techniques have shown that the renal arteries constrict vigorously during breath-hold dives, and the special morphological character of their innervation is therefore of unusual interest.

Some special aspects of temperature regulation of marine mammals have attracted attention. The circulatory mechanisms for maintenance of thermal balance in seals and porpoises are being explored. These investigations have led Drs. Douglas D. Hammond, David M. Denison, and Robert W. Elsner to study the special features of adaptation of newborn Weddell seals to their extremely harsh Antarctic environment.

Dr. Walter F. Garey led investigative studies of the functional biology of salmon in their spawning grounds in British Columbia. He continues his physiological studies of freely swimming sharks and also coordinates the research activities of the R/V *Alpha Helix* in his capacity as co-principal investigator for the *Alpha Helix* Program.

Regulation of body temperature in vertebrates is accomplished by temperature-dependent neurons in the basal forebrain and hypothalamic nuclei. How these neurons are affected by sensory inputs from temperature receptors in the skin and from proprioceptors in muscles and joints, how they are affected by sleep and by hibernation, and how they activate behavioral and autonomic thermoregulatory responses are questions which Dr. Harold T. Hammel and his associates are investigating.

While they were aboard the R/V *Alpha Helix* at Palmer Station, Antarctica, Dr. Larry I. Crawshaw and Dr. Hammel experimentally heated and cooled basal forebrain tissue in a notothenid fish *(Notothenia coriiceps)* and found that its aversion to warm water was determined by both the cutaneous and the brain temperature. On the same expedition, they found that heating and cooling the preoptic and anterior hypothalamic (POAH) nuclei of Adelie penguins affected thermoregulatory behavioral and physiological responses. For example, when these nuclei in the brain of a penguin standing in ice water were heated, the bird ate ice. The ice eating ceased when the brain tissue was cooled. Dr. H. Craig Heller has been heating and cooling the same brain nuclei in ground squirrels *(Citellus lateralis)* and he found that POAH temperatures from 2 to 15° C had no effect on the animal in deep hibernation, whereas heating and cooling the POAH tissue had profound effects during arousal and in the euthermic state. Henri P. Cabanac has shown that the escape of the lizard *Teliqua scincoides* from a cold environment is a function of both central and peripheral temperatures. Dr. Hammel and Frank Sharp, a UCSD medical student, have been studying the activation of thermoregulatory salivation in the resting and running dog by heating and cooling the POAH tissue.

James E. Maggert and Dr. Hammel continued their investigation of the efflux of water from the cells of winter-hardened trees and shrubs during the freezing of twigs in a calorimeter. These data can be used to calculate the water permeability of the membrane complex.

Seal undergoes simultaneous brain wave and heart impulse measurements as part of diving physiology studies carried out by Physiological Research Laboratory.

Dr. Edvard A. Hemmingsen was senior scientist of the 1971 Antarctic Expedition of R/V *Alpha Helix* in which fifteen scientists from six universities were involved. The respiratory physiology of the ice fishes and the tolerance of these hemoglobin-free fish to elevated temperatures was the subject of investigation. The basic gas solubility relationships which have been studied in the PRL for many years proved of value in understanding the unique CO_2 and oxygen transport problems which have been overcome in the evolution of the nearly colorless ice fish.

Research activities of Dr. Gerald L. Kooyman for the past few years have dealt mainly with the behavior and physiology of deep-diving in birds and mammals. Recent studies have emphasized the importance of the effects of pressure on blood gas tensions, configuration of the small airways of the lung, and the process of lung collapse during compression and their re-inflation upon return to the surface. These studies are expected to be continued in the future as will be an investigation of some of the general aspects of the comparative morphology and physiol-

While aboard R/V Alpha Helix *in Antarctica, scientists from Physiological Research Laboratory studied brain tissue in local fish to determine aversion to warm water.*

ogy of the vertebrate lung. This interest stems from pressure studies with diving and terrestrial animals. The subjects of particular interest are pulmonary function and analysis of the structure of the peripheral airways. Another continued interest and area of study is temperature regulation in fur seals, sea otters, and aquatic birds during immersion. A major portion of the research has been carried out during recent Antarctic expeditions. Weddell seal dives lasting as long as 60 minutes and going to depths of almost 2,000 feet have been recorded.

Since the summer of 1970 and until now, the main research activity of Dr. Per F. Scholander in collaboration with Cdr. Manoel Perez from Institute de Pesquisas da Marinha of Brazil has been an experimental inquiry into the mechanism of imbibition and osmosis. In experiments with a magnetic fluid, it was possible to alter osmotic properties of a solution by an external magnetic field. In a related experiment the effect of gravity on osmotic equilibria was found to be measurable. A comprehensive publication on the subject included a reinterpretation of both imbibition and osmosis.

During January, 1971, Dr. Scholander participated in the R/V *Alpha Helix* expedition to the Palmer Peninsula, Antarctica, and, in collaboration with Dr. William L. Orris, studied colloidal osmotic pressures in penguins. Other studies focused on the possible transport function of myoglobin through determination of the rate of oxygen transport through thin layers of muscle tissue.

The research of Dr. A. A. Yayanos has focused on three areas. The volume of binary solutions of molecules with a biological importance has been determined to 2,000 atm. The data are useful for understanding the behavior of molecules in deep-sea organisms. For example, the partial molal volume of amino acids in aqueous solution increases with increasing pressure. The magnitude of the electrostriction of water by an amino acid decreases with increasing pressure, and the size of the decrease is dependent on the dipole moment of the amino acid. Secondly, a relationship has been found between the tensile strength of pure liquids and their surface tension. An agreement has been observed between values of the tensile strength calculated from this relationship and those inferred from high-pressure pressure-volume data with the use of an equation of state. Finally, a study has been initiated on the relationship of DNA synthesis to cell division in marine bacteria when incubated at 1 atm and at high pressures.

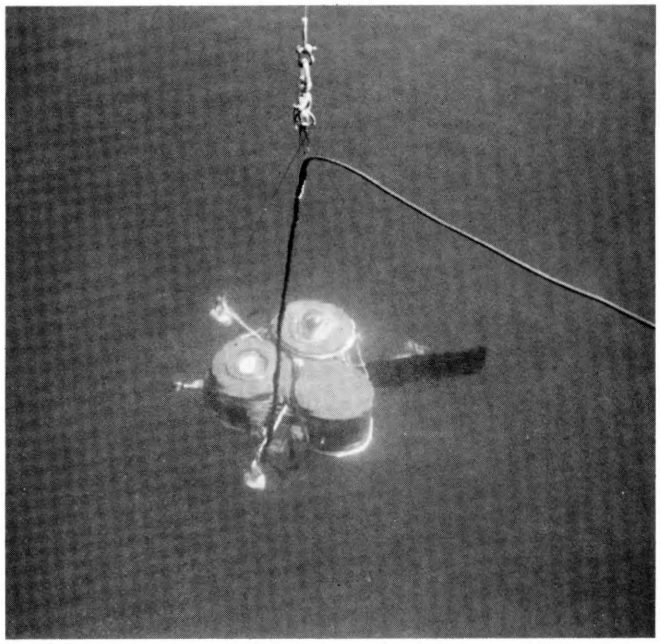
Visibility Laboratory

The scope of research conducted at the Visibility Laboratory covers the term visibility in its broadest sense: visibility in the ocean, on land, in the atmosphere, and in space. Laboratory personnel using the common scientific denominators of physics, mathematics, optics, and electronics, study aspects of visibility as varied as both image processing and remote sensing from outer space of ocean chlorophyll. This diversity is shown in the following representative projects underway at the Laboratory.

OPTICAL OCEANOGRAPHY. Optical oceanography and related studies remained a major activity at the Laboratory. Topics which have received particular attention during the past year are the propagation of narrow-angle light sources, the classification of ocean water by observable optical properties, the determination of the angular distribution of radiance in the ocean, and the remote sensing of ocean surface properties using visible region spectral energy.

The work of the past ten years by Dr. Seibert Q. Duntley and his colleagues on the propagation of laser light and other underwater sources over long path lengths was summarized in a major report issued in June, 1971. The studies were supported by measurements in lake water and most recently in a relatively small laboratory tank in which careful simulation of scattering and absorption properties allowed the scaling of the measurements to represent propagation paths of hundreds of meters in clear ocean water.

John E. Tyler continued his research efforts to develop a classification of ocean water types that could be easily identified at sea by simple optical measurements. Numerical identification by such means would lead to estimates of both biological and physical quantities typical of the water type. To accomplish this, large amounts of data are required on water of various types; the data can then be analyzed by computer techniques to determine those optical measurements that will best differentiate water types. Data for this effort have been accumulated from the various oceanographic cruises in which the Visibility Laboratory staff has participated, the most recent being the Fresnel II cruise to the Gulf of California in March and April, 1971. To obtain baseline data, Tyler made a study of the spectral values of the major optical properties of clean water. Tables of these properties based on quantitative data taken in clean natural bodies of water were prepared.

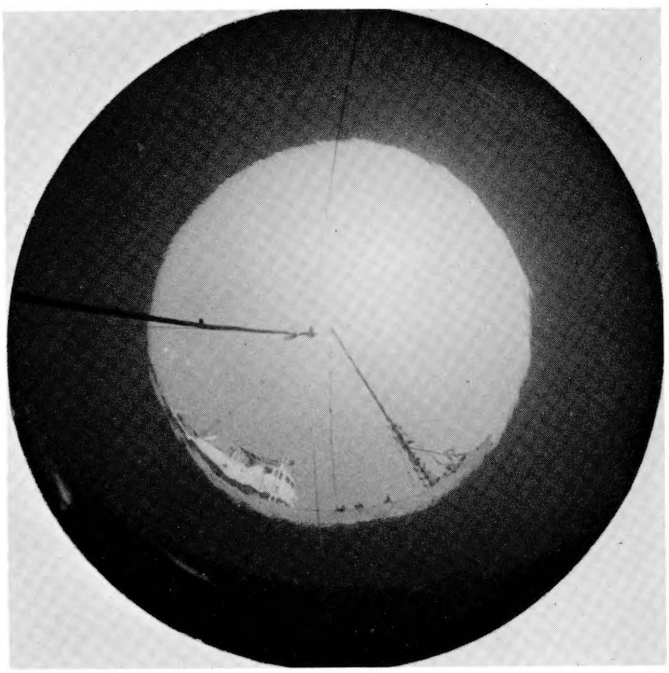


Visibility Laboratory camera system (submerged here about 1.5 meters) records angular distribution of underwater sunlight to see how much radiant energy is available for photosynthesis.
—Visibility Laboratory

During the Fresnel II cruise and again on a cruise of the R/V *Helland Hansen* in the Mediterranean Sea, Dr. Raymond C. Smith, using a unique dual fisheye camera system, collected photographic data from which the angular distribution of the natural light field may be determined. Scanning of the film and computer reduction of the data are currently in progress. Contemporaneous documentation of other optical properties was obtained. The total body of data should play a significant role in furthering the understanding of radiative transfer and image transmission in the ocean, as well as providing data for the solution of specific research and engineering problems.

In progress are several investigations into various aspects of remote sensing of the oceans by using the visible spectral region. The possibility of detecting ocean areas having high concentrations of chlorophyll by means of the apparent spectral radiance signature may provide a means of locating potential fishing grounds. In other studies by Dr. Duntley, Catherine F. Edgerton, and Almerian R. Boileau, indications are that a sufficient contrast would be available at orbital altitudes to allow the detection of small changes in chlorophyll *a* concentrations. These analyses were made for several typical maritime atmospheres and for water having chlorophyll levels in the lower range of interest to fisheries.

Another facet of the remote sensing effort is the work of Roswell W. Austin to determine the relationship between ocean surface reflectance and windspeed in the non-glitter regions. He used aerial photographs, obtained under situations in which windspeed exposure and other experimental parameters were carefully determined, to study by densitometry and computer analysis, the reflectance properties of the surface (i.e., the effect of white water). In addition, Austin performed several experiments



Attached to a ship by supporting cables, camera system took this picture looking straight up from underwater depth of 1.75 meters. The sky appears as a bright center circle. Darker outside ring represents the underside of the water surface, and the crescent at the bottom is an inverted view of ship's hull. Superstructure of the ship along with the boom and supporting cables for the camera system are also visible. —Visibility Laboratory

wherein "surface truth" optical, physical, and biological data were obtained from a ship while aircraft measured the observable optical signal from above. These experiments were directed toward understanding the capacity of remote sensing techniques for detecting subsurface oceanographic features.

ATMOSPHERIC VISIBILITY. One of the long-range programs conducted by the Visibility Laboratory is the study of atmospheric visibility and its relationship to the concurrent meteorological condition of the aerosol. A major activity in this regard is an experimental program of data collection and analysis leading toward obtaining a body of data suitable for direct application in visibility calculations. To this end, improved techniques are being devised for computational solutions under both real and idealized atmospheric conditions. At the same time, the extensive data bank of real-world measurements of atmospheric optical properties accumulated by the Laboratory is being processed to optimize computer retrieval and application.

During the past year, several field expeditions were conducted in direct support of this program. The sites ranged from central New Mexico to northern Michigan and southern Illinois. In all three instances, radiometric instrumentation designed and fabricated at the Laboratory was used on the ground and in an aircraft for the field measurements.

Although the main thrust of the data collection and analysis is directed toward acquiring more complete understanding and specification of the real-world atmospheric optical properties which are uniquely related to the solution of visibility calculations, there are also sidelines of cooperative activity in related fields. Aside from Laboratory applications, the measurements made during the expedition to central New Mexico, for example, are being used by the National Weather Service as comparative data in the evaluation of various computer-oriented analytic models of the lower atmosphere.

Similarly, the measurements conducted in southern Illinois were coordinated with Program METROMEX, multigroup investigation into the effects of the urban complex upon regional weather and pollution patterns. Participating scientists and technical teams were organized through the Illinois State Water Survey and included groups from the University of Chicago, Chicago, Illinois; the Argonne National Laboratory, Argonne, Illinois; the University of Wyoming, Laramie; Battelle Northwest Laboratories, Richland, Washington; and the Stanford Research Institute, Menlo Park, California.

VISION RESEARCH. Under a contract with the U. S. Coast Guard, Dr. John H. Taylor has begun a series of investigations into the detectability of flashing signal lights for maritime application. The variables under study include duration, color, and shape of the flash; the experimental results will find direct application in the specification of aids to navigation. It has become evident that established methods for specifying the effective intensity of flashing lights in terms of their fixed-light equivalents are not suitable for the evaluation of modern light sources. This may be particularly true in the case of the ultrabrief pulses or pulse trains from gaseous discharge lamps. The study is of special interest to the Commission Internationale de l'Éclairage and to the International Association of Lighthouse Authorities, and it is believed that results will be of use to the international signaling community.

IMAGE PROCESSING. On-going research in computerized image processing at the Laboratory may be divided into four categories: information-extraction experiments, analysis of visual performance, simulation of electro-optical systems, and basic improvements in computer image processing.

INFORMATION-EXTRACTION EXPERIMENT. During the course of the image processing research, the lurking question, Is image processing really helpful?, was confronted. To seek an answer, an information-extraction experiment was set up to test the ability of the human observer to gather, or decode, information from degraded pictures. The computer was then given the same task using the same images. The two results were compared, and a range of conditions was clearly established within which the computer can serve to make information previously undecodable apparent to the human eye.

VISUAL PERFORMANCE AS A FACTOR IN AIR-COLLISION AVOIDANCE. As aircraft become faster and more numerous, a problem of increasing importance is that of aircraft collision. James L. Harris takes one approach by the basic principles and techniques of computerized image processing to achieve a solution. The fundamental question is how does a flight crew identify an approaching plane soon enough to 1) determine whether it is on a collision course and 2) take successful evasive action if it is needed. (The lower working limit for an effective human response to these tasks is 10 seconds.)

To answer this question a comprehensive study of four interrelated variables seems to be necessary. They are: 1) the inherent optical properties of the approach craft, 2) the atmospheric properties intervening between the air crew and the approach craft, 3) basic human visual performance, and 4) human visual search technique.

Dramatic developments in computer capabilities the past five years now enable the Laboratory to specify the maximum performance of the human visual system in postulated air-collision circumstances and to optimize the above variables to aid in that performance. Unfortunately, only one of the variables can be controlled: the human visual search technique. This includes the size of the visual field to be searched, the effective range at which the search should begin, the percentage of crew duty time that can be devoted to search, and the mechanical restrictions and optical quality of windshields. Because this control faces several constraints, substantial attention is given to proximity warning indicator devices which seek to tell air crew when and where to search for a potential collision craft. Basically, the Laboratory is striving to optimize the one controllable variable (visual search technique) for a wide range of the remaining variables in order to guide the evolution of optimum collision warning indicator systems for use by commercial and general aviation. The National Aviation Safety Board, the Federal Aviation Agency, and other responsible governmental bodies are the recipients of the research results.

Important by-products of the Laboratory's research on air collision avoidance are computer-generated movies which re-create air collisions that have actually occurred and illustrate the effects of changing the above-mentioned variables. These films have

proven to be useful in accident analysis studies and in air crew training.

SIMULATION OF ELECTRO-OPTICAL SYSTEMS. An electro-optical system is a complex combination of optical and electronic components which produces an image of a scene on a cathode-ray tube display. Computer simulation of such a system allows inspection of the imagery at any stage of the process from the original scene to the final display. Many design changes in an electro-optical system can be considered for the purpose of improving the system performance. Such changes are often expensive and are usually highly uncertain with respect to their actual effect on system performance. In a computer simulation, such changes can be introduced inexpensively, and their effect on system performance can be evaluated by observers who view the simulated output display.

Marine Life Research Group

For many years the Marine Life Research program at Scripps concentrated its resources on the ecology of the California Current system. In recent years the program has been broadened to other areas that affect the California Current and are of interest to the State of California. The following are short reports on only a few of the members of Marine Life Research Group. Other reports were given in the SIO 1970 *Annual Report.*

Tetsuo Matsui and Dr. Richard H. Rosenblatt have recently begun a study of the little known life history of sablefish and grenadier off southern and Baja California. In the deep waters off Baja California and southern California, sablefish *(Anaplopoma fimbria)* are usually found between 200 and 800 fathoms. The depth of these fish decreases to the north off Oregon and Washington through to Alaska where they are fished commercially. Off California, there is almost no fishery for sablefish because they inhabit only the deeper depths.

Grenadier appear at mid-depth of the sablefish range and continue to the deeper depths of the ocean (at least to 3,200 fathoms). These are not all the same species. The species *(Coryphaenoides acralepsis)* off southern California appear about 500 fathoms and are found to at least 1,300 fathoms. This species is a wide-ranging fish and it is also found off Japan.

The compelling need to study the life history of the sablefish and a grenadier off southern California is that no eggs, larvae, or small fish have been found. These two fishes constitute a very large portion of the fish population at these bottom depths.

One of the very interesting findings so far in this study is that most of the males and females are separated geographically. Sablefish and grenadier taken at selected stations since February, 1971, have been mostly females; for grenadier the ratio has been roughly 5:1. The males have been much smaller than females. From a station in April, 1970, off Gudalupe Island, all 12 grenadier taken were males as large as most females, and one was nearly as large as the largest female caught to date. Of four stations where males dominated, only one had a female. Plotted on a chart, the distance between male-dominated and female-dominated areas is not distant. The few grendaiers taken in trawls show a more equitable sex ratio. This segregation by sex in these two species is not found in the literature. This research is continuing to determine more about the sex ratio at various locations and to look for the eggs, larvae, and young fish.

Estimates of total primary production in the ocean may have to be revised upward, according to the research of Dr. John A. McGowan, Dr. Elizabeth L. Venrick, and Arnold W. Mantyla. Most of the past work on total primary productivity has been based on data that were taken above 25 meters, and over half of the measurements were made only from sea surface data. All values of total production in the water column are strongly dependent upon the assumed (usually) depth of zero productivity. This is traditionally taken to be the depth at which the light intensity has been reduced to 1 percent of the incident radiation, and this criterion has been used to divided the water column into a euphotic zone and an aphotic zone. From their research it appears that the deep chlorophyll maximum occurs below the depth of penetration of 1 percent of the incident surface radiation most of the year in the major central gyres of both the North and South Pacific. It may account for a major portion of the standing crop of plant material and for a substantial portion of the primary productivity. The total rate of production throughout the water column is variable on rather small spatial and temporal scales, but appears to be considerably greater than maximum estimate of 100 mg $C/m^2/day$ estimated by Koblentz-Mishke and others. From the present data it is expected that similar chlorophyll maxima are well developed in other large, persistent temperate gyres, such as the southern Atlantic and Indian Oceans. If found, the estimates of world ocean primary productivity will need to be revised upward.

Joseph L. Reid continued a study of the abyssal circulation of the world ocean. Work at sea during this period included 42 days aboard R/V *Thomas Washington* in the Antarctic Ocean south of New Zealand. The immediate purpose of the expedition was to

Researchers Walter R. Schmitt and Peta Mudie use conductivity meter to check salinity level of seawater solution in which experimental table beets grow. Careful laboratory controls are necessary during seawater irrigation experiments directed by Marine Life Research Group.

Free-vehicle camera developed by the Marine Life Research Group took picture of shark at 640-meter depth in the Indian Ocean off Central East Africa during Antipode Expedition.

make long series of measurements (15–26 days) of the velocity near the bottom of the ocean (about 3000 meters in the area studied) and in particular to confirm an estimate of flow toward the west near the coast of Antarctica. The larger purpose was a continuation of the studies of Antarctic circulation carried out earlier in the Drake Passage; these studies are part of the general study of the exchange of water between the Atlantic, Indian, and Pacific Oceans through the Antarctic Circumpolar Current.

Westward flow was found in the deep waters close to Antarctica: the very cold and salty water from the shallow Ross Sea was observed to be moving westward across the Macquarie-Balleny Rise. In addition to the detail near Antarctica, the results have been combined with earlier results to provide a map of the surface currents of the Antarctic Ocean (geostrophic flow at the sea surface relative to about 1000 meters depth) in the Pacific sector south of 40°S. This clearly reveals the nature of the westward flow that exists south of the main eastward flowing Antarctic Circumpolar Current.

In another study the contribution of the Atlantic Ocean (Norwegian Sea and Weddell Sea) to the bottom waters of the North Pacific was shown. The very saline waters of the North Atlantic are traced into the Antarctic and then eastward with the Antarctic Circumpolar Current (where they are cooled and freshened) into the South Pacific and northward into the North Pacific.

The first phase of the Halophyte Program, under the direction of Prof. John D. Isaacs with the assistance of Walter R. Schmitt and Peta Mudie, is nearly completed. It was clearly demonstrated that some plants can be grown in seawater. Table beets were grown to maturity in seawater after they were started in fresh water for the first two months. Other plants being grown in various concentrations of seawater are Swiss chard, broccoli, bell pepper, cherry tomato, celery, marguerite, calendula, stock, statice, and sea pink. As expected, some are doing better than others. These plants are being grown in sand or hydroporic solutions.

The specific objectives of the first phase of the programs are: 1. examine and evaluate accepted concepts regarding factors controlling plant growth under saline conditions; 2. demonstrate growth in seawater of economically important plants; 3. evaluate, under controlled conditions, related work on seawater irrigation; 4. examine the opportunities for exploiting the genetic salt tolerance of halophytes through hybridization or graftage of related economic taxa; and 5. elucidate research opportunities for improving salt resistance of plants. Professor Isaacs points out that the greatest potential of the experiments with salt water may be the eventual hybridization of the salt tolerant plants, or "halophytes."

Neurobiology Unit

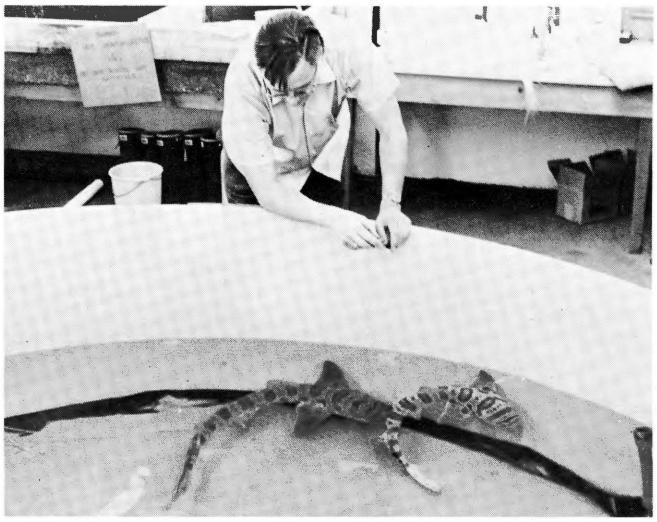
Dr. Theodore H. Bullock and his collaborators completed another phase in the study of echolocation mechanisms in auditory centers of the brain of porpoises. They implanted electrodes in cooperating, trained animals. For comparison, they also completed a series of similar sea lion studies.

Electroreception and its significance in the behavior of fresh water and marine teleosts and elasmobranchs is the common denominator of a series of studies by Drs. Bullock, Henning Scheich, Adrianus J. Kalmijn, Robert H. Hamstra, Jr., and collaborators. These studies range from single-unit recording in the brain using ultramicroelectrodes to behavior of free-swimming fish in tanks with their own electric fields or imposed electric fields.

Dr. Paul S. G. Stein is studying the organization of motor command and the coordinating neurons that join different segments in metachronal rhythms of appendages in arthropods.

Dr. Horst O. Schwassmann studied the development of visual pathways in fish regenerating from specific germinal zones in the retina and in the midbrain. He and Detreich L. Meyer also studied single units in the fish visual system to measure the accommodation of the eye by recording the responses of these units to fine wire targets at different distances in a long tank.

Dr. Robert W. Piddington found that fish can show in a conditioning task their ability to distinguish a click from the same click inverted, i.e., initial rarefactions versus initial compression—



Dr. Adrianus J. Kalmijn from the Neurobiology Unit tests California leopard sharks to determine whether or not they use their electric sense for navigation.

unlike ourselves. This gives the fish ability to distinguish approach from recession of another fish whose tail flip sends a compression first wave to the rear but a rarefaction first wave to the front. Dr. Piddington also studied the control of higher centers in the brain of the auditory input at lower levels.

Dr. James F. Toole, a visiting professor of neurology from the Bowman-Gray School of Medicine, Winston-Salem, North Carolina, followed up work of R/V *Alpha Helix* during Scripps's Amazon Expedition of 1967 by examining the neuromuscular system in the two-toed and three-toed sloths toward understanding the basis of slothfulness. Dr. Bullock led a party of six UCSD scientists to the jungles of Panama last year to further this study by examining electrical responses in the brain.

Dr. John E. Byrne examined the behavioral and physiological aspects of locomotor activity rhythms in teleosts. Recent experiments with the salmon *Oncorhynchus nerka* indicate that photoperiodic information which synchronizes the onset and termination of swimming activity is mediated only by the eyes and that melatonin and serotonin may play a role as chemical mediators; possibly an active agent is produced by the eyes and mediates the locomotor activity response to photoperiod. The senorita fish, *Oxyjulius californica,* burrows in the sand, becomes immobile during the darkness, and emerges from the sand with increasing light intensity. Although usually day active, a night response can be induced by increasing the temperature. This species promises to be a valuable experimental subject for studies on the neurophysiological and neurochemical basis of activity rhythms.

Dr. Kajuro Shimizu worked on the crustacean compound eye. He compared the performance of a model with measurements from shrimp eyes with respect to the optics of image formation.

Dr. Maryana Henkart, collaborating with Dr. Susumu Hagiwara, continued studies of the structural basis of the triggering of excitable muscle cells when, as a result of some stimulus, there is an increase in the permeability of cell membrane to calcium ions. Among the competitive inhibitors of calcium in this action is the lanthanum ion, which is favorable for localizing sites of binding in the electron microscope. The specific distribution of dense lanthanum particles with respect to surface features of muscle fibers in different states of activity is being analyzed with the electron microscope.

Drs. G. David Lange and Peter H. Hartline are recording the electrical activity of signaling response of the octopus and squid photoreceptors in the eye and optic ganglion in the brain and outbound controlling messages from the brain to the eye. With carefully controlled regimes of illumination, they have determined transfer functions under a number of conditions. Some of these conditions are possible only aboard ship where squid can be obtained in suitably fresh condition and studied within minutes of

capture. This has proven to be quite feasible even with the extremely delicate techniques required. Collaborating with Dr. Lange, Dr. Katerina Borer developed techniques and started experiments to train octopus to discriminate between flashing and steady lights. Linda J. Ball also took part in this work.

Christopher J. Platt is investigating the relations between input from tilt receptors and eyes in flatfish. A change has occurred in these species compared to standard fishes, a change associated with migration of the eyes and adoption of the habit of lying on one side. During this metamorphosis, which takes place during transition from the juvenile to the adult, there is probably a set of changes in the connectivity of the reflexes in the central nervous system.

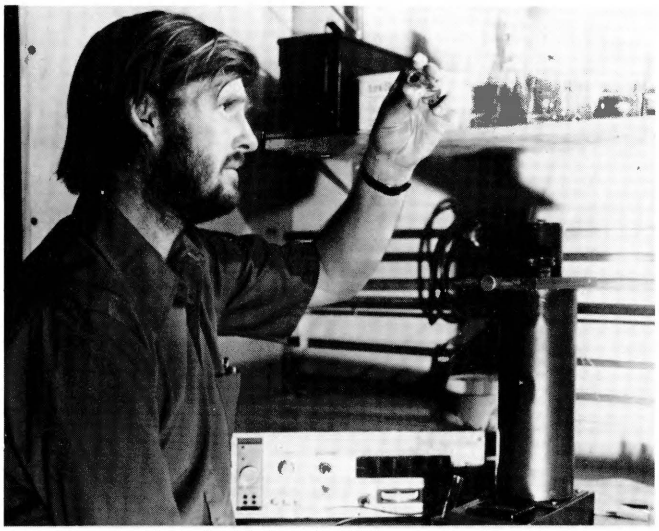
Institute of Marine Resources

SCRIPPS TUNA OCEANOGRAPHY RESEARCH PROGRAM. The Scripps Tuna Oceanography Research program, under the guidance of Dr. Maurice Blackburn and his associates, Drs. William H. Thomas, Francis Williams, and Mizuki Tsuchiya, is oriented toward establishing a scientific basis for improving the effectiveness of the tuna fisheries. Investigations in physical, chemical, and biological oceanography of the eastern tropical Pacific and adjacent waters are being conducted as a basis for understanding, explaining, and possibly forecasting changes in abundance, distribution, and amenability to capture of skipjack, yellowfin, and bluefin tunas in the present fishery regions and as a basis for identifying possible new fishery regions for these species. The most important properties affecting adult skipjack are water temperature and concentration of forage. The temperatures most favorable to skipjack appear to be 20° to 29°C. There are large areas in the eastern Pacific where these temperatures are found but the forage concentrations are variable. From the various cruises carried out during the year and earlier a model of skipjack migration is being developed.

MARINE FOOD CHAIN RESEARCH GROUP. The Marine Food Chain Research Group is concerned with the dynamics of the initial stages of the pelagic food chain. The principal investigators of the group are Drs. John R. Beers, Angelo F. Carlucci, Richard W. Eppley, Osmund Holm-Hansen, Michael M. Mullin, and Peter M. Williams. Dr. John D. H. Strickland, who started and headed the group, died in November, 1970.

The ultimate objective of this research is the construction of predictive models of various trophic interactions within the plankton. It is clear that a detailed model of the whole system is unlikely to be forthcoming in the near future, but a sufficiently detailed understanding of sections of the food web for simplified models to be applied is a realizable goal. The results of this research are increasingly better able to assist the fisheries biologist in evaluating those terms in stock recruitment and survival models that depend on food levels. Representative value on routes, rates, and efficiencies of transport from one trophic level to another of contaminants are becoming available for the biologist concerned with the possible transfer of these contaminants through the food web.

Dr. Osmund Holm-Hansen uses biophotometer to measure the amount of ATP (adenosine triphosphate) in samples of ocean water. Because ATP is present only in substances containing living bio-mass, this measurement is important in Institute of Marine Resources studies of the dynamics of the marine food chain.



SEA GRANT PROGRAM. The Sea Grant Institutional Program, a joint effort of UCSD and San Diego State College (SDSC) managed by Scripps, was in a state of transition during the year 1970–71.

Sea Grant programs were established by federal act in 1966 to encourage education, research, and advisory services for the better utilization of marine resources. Scripps joined with the Department of Aerospace and Mechanical Engineering Sciences and the Department of Applied Physics and Information Science of UCSD in 1968 to initiate its first Sea Grant program, the development of a new interdepartmental curriculum in Applied Ocean Science. In 1969, the scope of the program was expanded to include applied research projects.

In 1970, UCSD joined with San Diego State College to initiate a Sea Grant "Institutional Program," including graduate education and technician training, public advisory activities, and research in a broad spectrum of applications of science to resource utilization. At the time the program was prepared, UC President Hitch requested that the designation as a Sea Grant Institution be applied to the entire University of California rather than to the San Diego campus alone. Accordingly, a major portion of the year's administrative activities was devoted to preparation of a state-wide program for 1971–72 with activities to be initiated at six additional UC campuses and with administrative responsibility to be transferred July 1, 1971, to the University-wide Institute of Marine Resources.

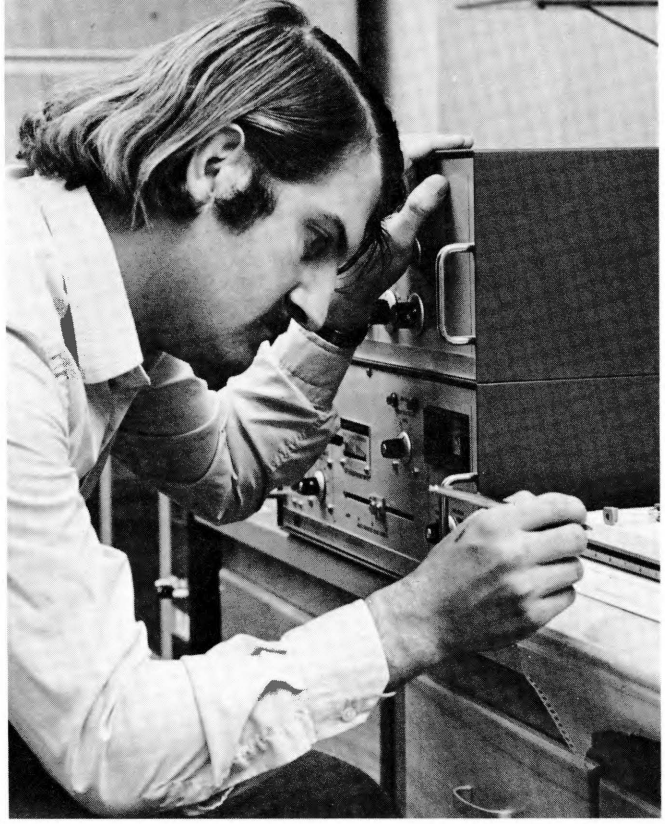
In keeping with the flexible decentralized organization of Scripps, most Sea Grant activities have been carried out within the existing laboratories and divisions of Scripps and are reported in greater detail under the various research divisions.

The original Sea Grant activity, development of an interdepartmental curriculum in Applied Ocean Science, was headed by Dr. Victor C. Anderson. Four new courses and a continuing seminar were initiated, and 23 students were enrolled in the curriculum. (Most of the AOS students are working on Sea Grant research projects listed later.)

Dr. Robert W. Elsner is initiating education and research programs in diving physiology in cooperation with the UCSD School of Medicine (see PRL section). James R. Stewart, Scripps diving officer, carried out training programs for individuals from federal agencies and other Sea Grant institutions, and he prepared an updated version of the *Diving Safety Manual.*

A large number of staff members cooperated in preparing sections of the Marine Technicians' Handbook, a general instruction manual in methods of gathering scientific data at sea; nine chapters were issued as separate sections. As an experiment, five students from marine-related undergraduate programs at San Diego State College participated in marine technician training along with Scripps technicians; they gained work experience at sea and ashore. A study was made by University Extension of the need for oceanographic training by practicing engineers in the San Diego community. To bring marine science to the public schools, the Vaughan Aquarium-Museum was assisted in providing classroom materials and guide service at the Aquarium-Museum for school groups. A service to industry designed to make Scripps marine geological data available to outside organizations was established by organization of the Geological Data Center under the direction of Thomas E. Chase (see GRD section).

Several Sea Grant projects were carried out with the cooperation of the Fishery-Oceanography Center of the National Marine Fisheries Service. Dr. Vance E. McClure, under the direction of Dr. Alan R. Longhurst, director of FOC, analyzed current and historical plankton samples for chlorinated hydrocarbons (DDT, DDE, and PCB) to determine the chain by which they have accumulated in the plankton and fish of the California Current Sys-



Dr. D. John Faulkner analyzes chemicals (potential pharmaceuticals) from starfish by gas chromatography as part of his ORD investigations and his Sea Grant research administered by the Institute of Marine Resources.

tem. Techniques were developed for the determinations in preserved samples and for separating and detecting chlorinated hydrocarbons in milligram samples.

Under the direction of Dr. Reuben Lasker, Dr. David L. Leighton is investigating the effects of salinity, heat, and DDT on the feeding and survival of larval fish. Methods were developed for routine spawning of anchovies and croakers in the laboratory, and new foods were developed for anchovies. Croakers were found to be more sensitive to the high salinities of Salton Sea water than to equivalent salinities of seawater; continuing studies are being made of the survival of croakers in water of varying salinities. Vance Holliday, a student in Applied Physics and Information Science, is studying the acoustic signature of fish in an attempt to improve the ability to classify fish by species and size using sonar.

A group of projects studying lobsters was carried out by San Diego State College as its part of the cooperative program, administered by Dr. Glenn A. Flittner. Work by Dr. David A. Farris at SDSC on the variations in the fishery for the California spiny lobster showed that an extremely high proportion of lobsters of legal size is caught each year, possibly as many as 50 percent. SDSC studies of California lobster pueruli by Dr. Deborah M. Dexter showed that juvenile and sub-legal lobsters can be maintained in laboratory conditions, and at elevated temperatures they can increase in size at double the natural growth rate.

Drs. Richard F. Ford and George O. Schumann are carrying out studies at SDSC of the growth of eastern lobsters in heated cooling-water discharges from the San Diego Gas and Electric Company power plant in South San Diego Bay and in normal seawater at Scripps; continued work by Dr. Ford in this program will be carried out using heated seawater at the SDG&E Encina power plant. The eastern lobsters survived and grew in tanks using water at and above the temperature of local ocean waters. Additional studies are being made on feeding habits and on interaction between the eastern lobsters and local species in order to study the possibility of introducing eastern lobsters into southern California waters. Drs. James H. Mathewson and Harvy Rabin of SDSC are studying pathogenic microbes and chemical residues in California spiny lobsters populations and the possible transmission of gaffkemia infection from eastern lobsters to California spiny lobsters. Dr. David J. Faulkner of Scripps and Dr. John D. O'Connor of UCLA are studying the effect of synthetic juvenile hormones (used as insecticides) upon lobster and crab populations.

A study of the possibility of using deep, cold ocean water for power plant cooling and discharging the effluent at ambient surface-water temperatures for aquaculture was initiated by Prof. John D. Isaacs and Walter R. Schmitt. They plan to use two bomb craters at Eniwetok as a test site. In related projects, graduate student Arthur Wolfson is studying the effect on marine life of heated power plant discharges both at the San Onofre nuclear power plant and in the laboratory at Scripps, and Ronald K. Lam measured the permeability of the coral substrate at Swain's Atoll.

Other studies of biological resources were carried out, one by Dr. James T. Enright and Hans-Willi Honegger and one by Professor Isaacs and Sargun A. Tont on the vertical migration of the deep scattering layer. Graduate student Theodore C. Tutschulte studied the growth and life habits of abalone. Dr. Carl H. Gibson is working on methods of improving the predictability of ocean surface water temperature in order to improve the National Marine Fisheries Service fisheries prediction service for the albacore fishery. Dr. Russ E. Davis is working on improved methods of wave prediction.

To improve capabilities for predicting the effects of man's activities in the coastal zone, Drs. Douglas L. Inman and Charles W. van Atta are developing new instrumentation for studies of near-shore physical processes. Dr. E. W. Fager is carrying on studies of the effects of ecological disturbances in sandy coastal areas, and Dr. Paul K. Dayton is studying similar effects in rock-bottom areas. Dr. William A. Newman is studying ecological disturbances on coral reefs. (These activities are reported more fully in the ORD and GRD sections.)

Ocean engineering efforts were carried out by Dr. Anderson using the RUM vehicle for ocean-bottom soil strength measurements (see MPL section) in cooperation with Dr. Iraj Noorany of San Diego State College. Professor Isaacs is making engineering studies of several types of breakwaters including "Non-Archimedean bodies" (submerged floats that dissipate wave energy) and artificial reefs.

Institute of Geophysical and Planetary Physics

The Institute of Geophysics and Planetary Physics (IGPP) is a University-wide Institute with branches at La Jolla, Los Angeles, and Riverside. 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, Dr. Hugh Bradner, and Sir Edward C. Bullard hold Scripps appointments; their offices are located at IGPP. Dr. Barry Block holds a joint appointment in IGPP and the Physics Department of UCSD. Dr. John W. Miles holds a joint appointment in IGPP and UCSD's Department of Aerospace and Mechanical Engineering Sciences.

Dr. Backus continues work on the geophysical inverse problem: given the frequencies of the Earth's normal modes, what can be inferred about the interior distribution of density and the elastic constants? (His contributions to this field earned him election to the National Academy of Sciences in 1969.) Dr. Backus is also working on propagation of elastic waves in anisotropic media. Thus far, he has demonstrated that Molchanov's observed "resonances" in the solar system are probably the result of chance.

Dr. Gilbert, who is studying the generalized ray theory for computing theoretical seismograms, is also planning a geophysical array to monitor the Earth's strain field in southern California. For the first time, Dr. Haubrich has been able to associate certain types of microseisms with traveling storms at sea. He has investigated and disproved the possibility that the observed wobble of the Earth is the result of major earthquakes.

Dr. Block has developed a horizontal broad-band accelerometer to complement the vertical broad-band accelerometer already

in operation. These instruments have been used in earth normal mode and surface wave studies. Measurements of surface wave detection thresholds were made both at the surface and deep mine sites.

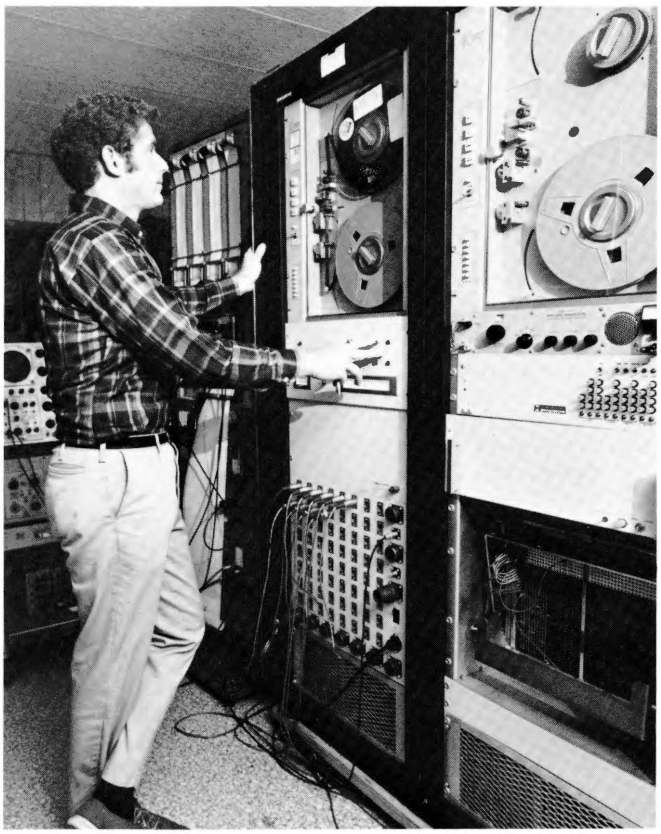
Drs. Ralph H. Lovberg and Jonathan Berger developed and deployed at the nearby Elliott Geophysical Observatory a laser interferometric strain meter of high sensitivity and exceptionally long-term stability. Studies are currently underway involving correlations among strain, tilt, and vertical displacement caused by earth tides, ocean and atmospheric loading, earthquakes, and nuclear detonations.

Dr. Berger continues his work in the development of the Piñon Flat Geophysical Observatory in the San Bernardino National Forest. This work has progressed with the installation of two axes of a three-axes array of laser strain meters. A low drift quartz accelerometer of the Block-Moore design and a LaCoste gravimeter will be installed in addition to a two-axes tiltmeter, a cryogenic gravimeter developed by Drs. John M. Goodkind and William A. Prothero of the UCSD Physics Department, and a microbarograph developed in Dr. Berger's laboratory. Studies to be conducted include investigations of the strain, displacement, and tilts caused by earthquakes; of earth tides; and of ocean and atmospheric loading. Particular attention will be focused on the slow buildup of tectonic strain that is expected in this high stress area.

Dr. Miles continues work on rotating flows, in which Coriolis force is of dominant importance; stratified flows over obstacles and internal waves in the thermoclines; and resonant response of harbors and bays to tsunamis.

Dr. Brune's field is earthquake mechanisms. He interpreted the various portions of earthquake spectra to provide information on total stress and stress release associated with various earthquakes. Jointly with scientists from the University of Mexico, he is investigating earthquakes in Baja California and may extend this work to a joint effort with Dr. Bradner to measure after-shocks with sea-bottom seismometers. Dr. Brune is associated with development of the Piñon Flat Geophysical Observatory.

Dr. Jonathan Berger checks seismic data recording unit at the Elliott Geophysical Observatory site as part of his research at the La Jolla laboratories of UC's Institute of Geophysics and Planetary Physics.



Electronic technician Charles W. Van Sice displays quartz vertical accelerometer used in earth normal mode and surface wave studies conducted by Dr. Barry Block at the La Jolla laboratories of UC's Institute of Geophysics and Planetary Physics.

Drs. Munk and Frank E. Snodgrass have completed their work on measuring deep-sea tides with self-contained, freely dropped, deep-sea instrument capsules. As a result of approximately 50 drops, they have given a description of the character of tides in the Northeast Pacific and Antarctic Oceans. The instrument capsules are now being modified to study internal waves. Also, a new capsule is being constructed that will remain on the sea floor for one year to study low-frequency fluctuations of pressure, temperature, and water velocity in the deep sea.

Advanced Ocean Engineering Laboratory

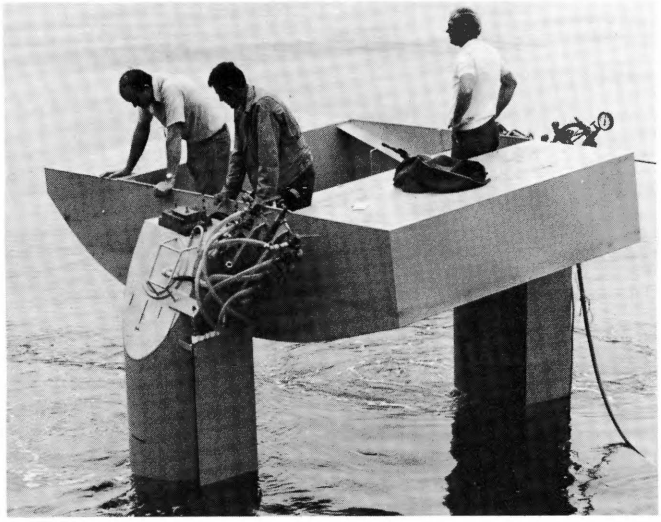
The Advanced Ocean Engineering Laboratory is responsible to the director of Scripps for conducting advanced engineering research in several diverse fields. Financial support to date has been from the Advanced Research Projects Agency (ARPA) of Washington, D. C., which has placed its contracting through the Office of Naval Research.

Five programs were active during the Fiscal Year 1971. Each was a result of meetings of the steering committee, which is chaired by Director Nierenberg, and approved by ARPA. These projects are: (1) Stable Floating Platforms (Dr. Fred N. Spiess, principal investigator); (2) Benthic Array (Drs. Walter H. Munk, Robert D. Moore, and William A. Prothero, co-principal investigators); (3) Over-pressures Due to Earthquakes (Dr. Hugh Bradner and Prof. John D. Isaacs, co-principal investigators); (4) Nearshore Engineering (Drs. Douglas L. Inman and William G. Van Dorn, co-principal investigators); and, (5) Electromagnetic Roughness of the Ocean Surface (Drs. William A. Nierenberg and Walter H. Munk), a cooperative effort with the Center for Radar Astronomy, Stanford University (under the direction of Dr. Allen M. Peterson).

The Stable Floating Platform Program was initiated to advance the technology by designing, building, and demonstrating the feasibility of large, stable floating platforms in the open sea.

The basic concept will be comprised of a four-legged platform made up at sea from two two-legged modules, each module consisting of a pair of FLIP-type legs rigidly connected to each other and supporting a superstructure platform on a trunnion so that the platform remains essentially horizontal as the legs are changed from the horizontal to the vertical attitude.

Of particular importance is the established objective of using post-tensioned concrete to the greatest extent possible as the structural material for the legs. Considerable progress has been



One-eighth scale model of Stable Floating Platform, designed and built under the direction of the Advanced Ocean Engineering Laboratory, demonstrates the feasibility of using large, stable research platforms in the open ocean. Several two-legged modules can be linked to form platforms of various sizes.

made with the ⅛-scale models of the platform which have been tested extensively in San Diego Bay. Detailed tests of 1/100-scale models have been made in the wave channel in Scripps's Hydraulics Laboratory. Measured responses have been in close agreement with theory.

The proposed platform would have a number of attractive features for support of ocean engineering work. The large deck area would be useful for assembling and stowing experimental equipment. Lowering and raising these items of equipment through the air/sea interface and on down to desired depth would be a useful application for a number of programs. The availability, in a stable platform at sea, of additional important support features such as living and working spaces for a scientific party, a general purpose computer, and a moderately large source of power, would be of great importance to a number of programs.

The goal of the Benthic Array Program is to adapt the high-performance, quartz vertical accelerometer developed by Drs. Moore and Barry Block at La Jolla Laboratories of the Institute of Geophysics and Planetary Physics for use on the ocean bottom, thereby increasing the technology of ocean-bottom instrumentation as well as providing an increased scientific understanding of the properties of the earth below.

Specifically, an instrument package is being constructed that will enable the quartz accelerometer to be operated on the ocean bottom to depths of 20,000 feet. The package will be completely self-contained, including all necessary power supplies, electronics, data recording acoustical control, and telemetry systems. It will be capable of operation without surface support for periods of 7 to 30 days. The package has entered its final assembly stages with most of the design problems solved. Testing of the complete package in a vault is scheduled for the fall of 1971 and in sea trials beginning January, 1972.

The Overpressures Due to Earthquakes project work is directed toward the understanding of the various effects—at the sea surface, at the ocean floor, and between—of nearby undersea earthquakes. The goal has been the study of pressure variations in the water column that result from seismic events. At the beginning of the program various experimental approaches were considered, including the development of inexpensive long-time instruments that could be scattered over known seismic areas and left for extended lengths of time (i.e., several years). The idea of attempting to measure the overpressures using such instruments was subsequently abandoned, mainly because of the gross uncertainties involved with trying to make such measurements in the near field of adequate seismic activity. It was decided, instead, to attempt measurements during the aftershock sequence of large earthquakes located beneath the sea.

There is almost invariably a sequence of aftershocks following a large earthquake. By definition, the size of the aftershocks is all smaller than the main event (the greatest aftershock is usually about 1.2 in magnitude less than the main event) and continues for from a few days to a number of weeks after the main shock. They are usually located in the general region of the main shock and most probably along the edges of the displacement area of the main shock. Instrumentation has been developed for immediate delivery to a seaquake area in the event of seismic activity of the proper type and in an accessible location.

Nearshore engineering studies of the transport and circulation mechanisms which are cooperative in the nearshore zone increasingly emphasize the importance of the interactions among waves, currents, and sediments at the water-sediment interface. These studies concentrate on understanding of the wave-current interactions in terms of: (1) the velocity field of the water in nearbreaking and breaking waves; and, (2) the complex interactions in the boundary layer at the water-sediment interface. They have general application to the design of vehicles or structures intended to perform useful tasks within the surf zone, and particularly to the problems of sand and sediment transport and control.

A summary of the work done in the above two categories follows:

1. A laboratory study of the velocity and momentum fields in breaking waves, with the object of defining not only the particle displacements, velocities, and accelerations within individual waves, but also the net circulation induced by their combined interactions over representative beach slopes. Present progress includes: (a) completion of revised instrumentation for measurements, as a function of time and position, the flow velocity, the particle displacements and trajectories, the surface elevation, and the sub-surface pressure; (b) 80 percent completion of a series of flow measurements, comprising more than 1,000 test runs and 7,000 data points, taken within wave trains at four different periods and incident upon each of three beach slope angles. All data are programmed on punch cards for computer processing. Analysis of the data thus obtained is well under way; and, (c) design and partial construction of a portable instrumentation platform for field observations.

2. A field and laboratory study of the water-sediment interface under wave action that includes: (a) analysis and comparison of wave-induced boundary layer theories with previous laboratory investigations over both smooth and rough bottoms; (b) measurement of the interface geometry and interpretation of motion films of particle movement at, and above, a naturally rippled water-sediment interface in the Pacific Ocean, and on an intermediate scale near the surf zone in the Gulf of California, Mexico; and (c) construction and testing of phase-dependent roughness elements in the Hydraulics Laboratory wave tank.

The Electromagnetic Roughness of the Ocean Surface program as assisted by Stanford University is involved in a program to use radar to measure the statistical properties of ocean waves, particularly the ocean-wave directional spectrum. The immediate goal was the testing of various methods of measuring the ocean-wave direction spectrum using LORAN signals in preparation for future field experiments using multifrequency, pulsed Doppler radars. The methods to be investigated were monostatic geometry with an antenna array, bistatic geometry with simple antennas, and monostatic geometry using a synthetic aperture (side-looking radar).

The major proportion of the work to date has been directed toward the construction of equipment necessary to investigate these methods. The remainder has been concerned with planning an experiment designed both to test the bistatic method and to obtain good directional spectra of ocean waves, writing computer programs to analyze these data, and examining the mechanisms producing second order scattering of radio waves from ocean waves (and its importance in the experiments).

The administrative staff of AOEL includes Gerard H. Fisher, manager, who replaced Marion W. Johnson, who retired December 31, 1970; Lawrence E. Beaver, who joined the group in January, 1971, as the administrative officer; Dyantha T. Yarbrough, administrative assistant; and Martha J. Cauthen, clerk-typist.

SHORE FACILITIES AND COLLECTIONS

The very nature of the research and graduate instruction under way at Scripps implies a requirement for special facilities and collections. There follow, coded to an accompanying map, brief descriptions of the Institution's principal shore facilities and collections.

Facilities

Thomas Wayland Vaughan Aquarium-Museum (5). The Aquarium-Museum provides an important public service as a division of Scripps open to the public on a daily basis. Displays of living marine animals and varied museum exhibits present and interpret current ideas and research on marine biology and oceanography.

The staff, assisted by nearly 100 volunteer docents, conducts a manifold educational program. In addition to 37,000 students who annually tour the Aquarium-Museum in educational groups, a career experience program is offered to high school and college students considering an aquarium career. Federal Sea Grant funds support a full-time coordinator for educational programs.

Although admission is free, voluntary contributions from many of the more than 300,000 yearly visitors provide significant financial support.

In May, 1971, a gift of $25,000 was pledged to the Foundation for Ocean Research by the Southern California First National Bank for the benefit of the Aquarium-Museum. New museum exhibits, expansion of educational programs, and a museum curator will be supported by these funds.

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 and Outfitting Shop (10). This shop is primarily involved in the design, development, and fabrication of research equipment and instrumentation in support of the various departments at Scripps, the Fishery-Oceanography Center of the National Marine Fisheries Service, UCSD, University Hospital, 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 government and institutional scientific ships. The station has worldwide capabilities. Voice, W, radioteletype and facsimile transmissions can be handled by the station, which operates 20 hours a day, seven days a week. The station collects environmental data from the commercial fishing fleet operating in the eastern Pacific, and daily broadcasts and transmits fishing advisories and facsimile charts of temperature, wind and wave conditions in the fishing areas.

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, 1971, the library held 88,326 bound volumes, 40,186 maps and charts, 20,611 reprints, 16,732 documents, reports and translations, and 2,420 pieces of microscopy.

Hydraulics Laboratory (1). This laboratory is equipped with a wind-wave channel 140 x 8 x 8 feet with a simulated beach, and a tow cart for instrument and model towing; a 50 x 60-foot wave basin with an adjustable simulated beach; a 130-foot, glass-walled wave-and-current channel; and an insulated, refrigerated, cylindrical seawater tank 34 feet deep and 10 feet 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 1,000-foot 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 Fishery-Oceanography Center of the National Marine Fisheries Service.

Seawater System (15). The system provides seawater to Scripps and the Fishery-Oceanography Center. It utilizes two sand filters and two concrete storage and settling tanks, each with a 53,000-gallon capacity. Delivery capacity is 1,200 gallons per minute.

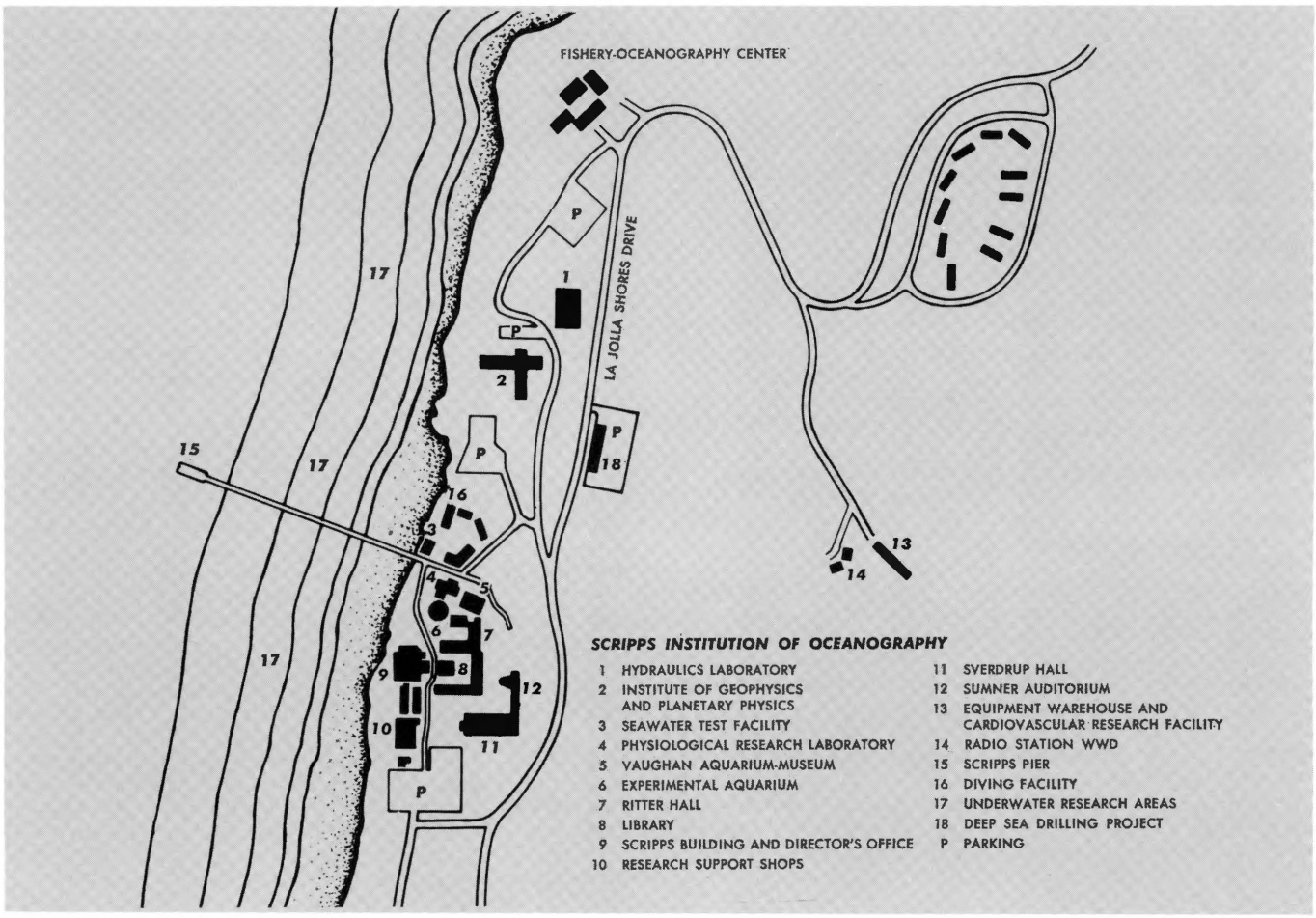
Electron Microprobe Laboratory (11). This laboratory permits the chemical analysis of volumes as small as one cubic micron at concentration levels above a few hundred parts per million. This is achieved by accurate spectrographic measurements of the X-radiation from the area analyzed, which is excited 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 40,000-cubic-foot air volume bank, diving cylinder storage, and an overhaul and repair facility. A 33-foot diving boat and a 16-foot 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 ten-year total of 50,000 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 ultrafine structure.

Darlene Hubbard is one of nearly 100 docents who volunteer their time at the Vaughn Aquarium-Museum. These instructor-guides annually tour 37,000 students through the facility.



Analytical Facility (11). Capabilities of the facility include: atomic absorption spectrophotometry, X-ray diffractometry, X-ray spectrography, emission spectrography, gas chromatography, spectrophotometry, high and ultra-high vacuum techniques, geochemical and geological sample processing, and microscopy. A new addition this year is a Cambridge S4 scanning electron microscope, which can magnify up to 200,000 times with a depth of focus at least 300 times greater than that of a light microscope. Also available at the facility are laboratory space and facilities and geological field equipment.

Mass Spectrographic Equipment (7) and (11). Six mass spectrographs are available, including two six-inch. Nier-type spectrometers for isotopic analysis of light elements; a 12-inch mass spectrometer for geochronology studies; an omegatron mass spectrometer for isotopic analysis of rare gases; 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.

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 the Scripps Clinic and Research Foundation, La Jolla, this facility consists of an experimental animal colony and equipment for phsyiological research involving measurements of circulatory and cardiac functions in free-moving animals.

Physiological Research Laboratory Pool Facility (4). This facility consists of a holding pool for large marine mammals and fish; a ring pool of 32-foot 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.

Soledad Mountain Laboratory (Mt. Soledad). This laboratory studies certain characteristics of the ocean and its organisms by measuring extremely small traces of natural and artificial radioactivity. The laboratory is an ideal center for certain biological, chemical, and physicial research programs that have been brought to this campus because it provides special research facilities as well as isolation from larger amounts of radioactivity which sometimes interfere with experiments.

Kendall-Frost Mission Bay Marsh Preserve (Mission Bay, San Diego). Approximately 20 acres of marshland in Mission Bay belonging to the University constitute a marsh preserve and wildlife refuge. Plans call for this land to be used for biological research.

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 a 24 x 50-foot enclosed platform moored in 40 feet of water offering 4,500 feet of unobstructed range.

Special Collections

Geological Data Center (5). Geological data collected by Scripps vessels concerning soundings and bathymetry, magnetic anomalies, and seismic reflection and refraction are indexed, compiled, and stored at this location. Also available are soundings from several hundred thousand miles of expedition tracks through all sectors of the Pacific Ocean and part of the Arctic Ocean.

Marine Vertebrates (Fish Collection 5 and 7). This consists of some 750,000 specimens of 2,500 catalogued species of marine fishes. Added in 1969 and 1970 were 900 collections of bathypelagic and shore fishes.

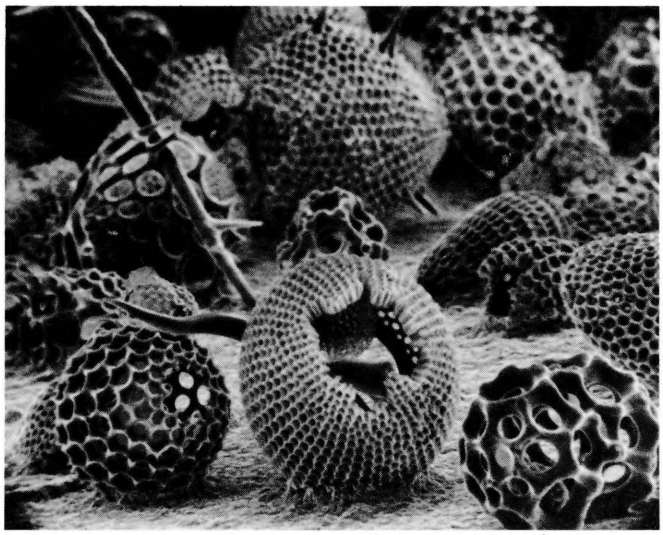
Marine Invertebrates (Zooplankton Collection, 5 and 7). In this collection are nearly 50,000 fully documented plankton samples; of these some 17,000 are from special expeditions and some 750 from deep-water Isaacs-Kidd midwater trawls. Samples are supplemented by full meteorological, hydrographic, physical, and chemical data.

Geological Samples (Storage locker is near Diving Facility). This collection contains some 4,000 geological samples, including 3,000 sediment cores. Also available for study are dredge-hauls of rocks and manganese nodules, taken mainly from the Pacific and Indian Oceans, and drill-cores near Guadalupe Island taken during the experimental Mohole operation.

Deep Sea Drilling Project Core Repository (Located in north end of DSDP headquarters). Scripps houses the West Coast Repository for cores collected by DSDP. The DSDP is part of the National Science Foundation's (NSF) National Ocean Sediment Coring Program, and these collections are a national archive. Cores stored at this repository come from the Pacific Ocean. (Cores from the Atlantic, Mediterranean, 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.

New Cambridge S4 scanning electron microscope at the Analytical Facility magnified and photographed these silica skeletons of radiolarians, single-celled marine animals. The microscope can magnify up to 200,000 times life size with a depth of focus at least 300 times greater than that of a light microscope.



PUBLICATIONS

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 1970–71, including information on their availability.

Bulletin

The *Scripps Institution of Oceanography, Bulletin,* which contains lengthy technical 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.

Bulletin volumes issued during the last year are below:

Volume 16: ALVARIÑO, Angeles. Siphonophores of the Pacific with a Review of the World Distribution. 1971. 429p.

Volume 17: STRICKLAND, J. D. H., ed. The Ecology of the Plankton off La Jolla, California, in the period April through September, 1967. 1970. 103p.

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: Gifts 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 109, La Jolla, California 92037.

ALFVEN, H. and Gustaf O. S. ARRHENIUS. Origin and evolution of the solar system, II. *Astrophysics and Space Science,* v. 9, 1970. pp. 3–33.

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Patent

Copies of the patent listed below, issued to a member of the Scripps staff, can be obtained for a small fee from the U. S. Patent Office, Washington, D. C. 20231.

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71-5 OLCOTT, H. S., John VAN DER VEEN, Barbara MEDWADOWSKI and Vega SMITH. Lipid composition of fish protein concentrate; annual report July 1, 1969–June 30, 1970. 1970. 21 p.

71-6 SMITH, Vega and Harold OLCOTT. Lipid composition of fish protein concentrate; first quarterly report July 1, 1970–September 30, 1970. 1970. 3 p.

Two Scripps graduate students participated in Department of Interior's Project Tektite II for two weeks in July, 1970. As members of America's first female underwater research team, they lived in and worked in and around a habitat moored 50 feet below the ocean surface in Great Lameshur Bay, off St. John Island, U. S. Virgin Islands. Shown as they give their new "home" its first decoration—an anti-pollution poster—are (left to right) Dr. Renata S. True, Tulane University Medical School, New Orleans, Louisiana; Ann Hartline, Scripps; Margaret Ann Lucas, University of Delaware, Newark; and Alina M. Szmant, Scripps. Not pictured is team leader, Dr. Sylvia Earle Mead, UC-Berkeley and Harvard University, Cambridge, Massachusetts.

71-7 SMITH, Vega and Harold S. OLCOTT. Lipid composition of fish protein concentrate; second quarterly report, October 1, 1970–December 31, 1970. 1971. 5 p.

71-8 SMITH, Vega and Harold S. OLCOTT. Lipid composition of fish protein concentrate; third quarterly report, January 1, 1971–March 31, 1971. 1971. 4 p.

71-9 THOMAS, William H. Effects of nutrients on growth of algae: Tropical oceanic plankton: Final report to National Science Foundation, March 1, 1969–February 28, 1971. 1971. 21 p.

71-10 Research on the marine food chain; progress report July 1970–June 1971. Part 1: Introduction and account of work in progress; part 2: Manuscript reports of work concluded; part 3: Data records; A. Cruise, Piquero, leg 7, section 2; the plankton; B. Physical, chemical and biological oceanographic studies off La Jolla, California. July 1971. 828 p.

STAFF *July 1, 1970 to July 30, 1971*

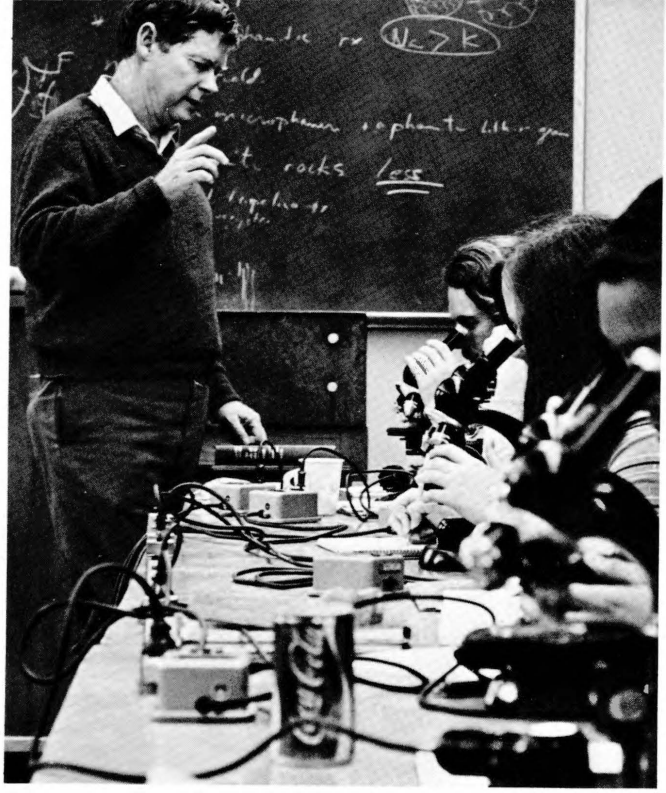
Name	Research Group	Field
#Elbert H. Ahlstrom	Department SIO	Biological Oceanography
Edwin C. Allison	Geological Research Division	Geology
Victor C. Anderson	Marine Physical Laboratory/ Sea Grant Program	Marine Physics
Gustaf O. Arrhenius	Geological Research Division	Oceanography
Robert S. Arthur	Ocean Research Division	Physical Oceanography
Roswell W. Austin	Visibility Laboratory	Optical Physics
Agustin Ayala-Castanares	Scientific Support Division	Biology/Paleontology
Farooq Azam	Marine Biology Research Division	Microbiology
George E. Backus	Institute of Geophysics & Planetary Physics	Geophysics
Jeffrey L. Bada	Institute of Marine Resources	Marine Chemistry
Arnold E. Bainbridge	Ocean Research Division	Marine Chemistry
Tim P. Barnett	Marine Life Research Group	Physical Oceanography
John L. Baxter	Marine Life Research Group	Oceanography
John R. Beers	Institute of Marine Resources	Marine Zoology
Andrew A. Benson	Marine Biology Research Division/Physiological Research Laboratory	Marine Zoology
Jonathan Berger	Institute of Geophysics & Planetary Physics	Geophysics
+Thomas Berman	Institute of Marine Resources	Microbiology
Hugo F. Bezdek	Marine Physical Laboratory	Physics
George S. Bien	Ocean Research Division	Chemistry
Rudolf H. Bieri	Geological Research Division	Physics
Maurice Blackburn	Institute of Marine Resources	Biological Oceanography
Barry Block	Physics/Institute of Geophysics & Planetary Physics	Geophysics
Brian P. Boden	Marine Biology Research Division	Marine Biology
Elizabeth Kampa Boden	Marine Biology Research Division	Marine Biology
Almerian R. Boileau	Visibility Laboratory	Atmospheric Optics
+Anthony J. Bowen	Ocean Research Division/ Sea Grant Program	Phyical Oceanography
Robert E. Boyce	Deep Sea Drilling	Geology
Hugh Bradner	AMES/Institute of Geophysics & Planetary Physics	Physics/Seismology/ Control Systems
*Milton N. Bramlette	Ocean Research Division	Geology
Edward Brinton	Marine Life Research Group	Marine Biology
Wendell S. Brown	Institute of Geophysics & Planetary Physics	Geophysics
James N. Brune	Institute of Geophysics & Planetary Physics/Geological Research Division	Geophysics
Sir Edward C. Bullard	Scientific Support Division	Geophysics
Theodore H. Bullock	Neurobiology Unit	Neurophysiology
John E. Byrne	Neurobiology Unit	Neurophysiology
Henri Paul Cabanac	Physiological Research Laboratory	Physiology
Angelo F. Carlucci	Marine Life Research Group	Microbiology
Richard M. Cassie	Ocean Research Division	Numerical Ecology
Thomas E. Chase	Geological Research Division/ Sea Grant Program	Marine Geology
Tsaihwa J. Chow	Ocean Research Division	Chemistry
Thomas M. Church	Geological Research Division	Marine Chemistry
James R. Clinton	Marine Physical Laboratory	Oceanography
Charles S. Cox	Ocean Research Division	Physical Oceanography
Harmon Craig	Geological Research Division	Geochemistry & Oceanography
Larry I. Crawshaw	Physiological Research Laboratory	Physiology

#Adjunct Professor
*Emeritus
+Visiting

Name	Research Group	Field
Joseph R. Curray	Geological Research Division	Marine Geology
Thomas A. Davies	Deep Sea Drilling	Marine Sediments
Russ E. Davis	Ocean Research Division	Physical Oceanography
Paul K. Dayton	Ocean Research Division/ Sea Grant Program	Biological Oceanography
Arthur L. DeVries	Physiological Research Laboratory	Physiology
E. Grey Dimond	Physiological Research Laboratory	Physiology
James I. Drever	Geological Research Division/ Institute of Marine Resources	Marine Geology
Seibert Q. Duntley	Visibility Laboratory	Physics
Lawrence A. Dyck	Marine Biology Research Division	Marine Microbiology
*Carl H. Eckart	Marine Physical Laboratory	Marine Geophysics
N. Terence Edgar	Deep Sea Drilling	Geology
Robert W. Elsner	Pediatrics/Physiological Research Laboratory/Sea Grant Program	Physiology
A. E. J. Engel	Geological Research Division	Geology
Celeste G. Engel	Geological Research Division	Chemistry
Theodore Enns	Marine Biology Research Division	Physiology
James T. Enright	Ocean Research Division	Biological Oceanography
David Epel	Marine Biology Research Division	Marine Biology
Richard W. Eppley	Institute of Marine Resources	Biological Oceanography
Martha W. Evans	Marine Life Research Group	Physical Oceanography
Edward W. Fager	Ocean Research Division	Biological Oceanography
William E. Farrell	Institute of Geophysics & Planetary Physics	Geophysics
David J. Faulkner	Ocean Research Division	Natural Product Chemistry
Jean H. Filloux	Ocean Research Division	Physical Oceanography
Frederick H. Fisher	Marine Physical Laboratory	Marine Physics
Robert L. Fisher	Geological Research Division	Marine Geology
John E. Fitch	Marine Life Research Group	Marine Biology
Wade L. Fite	Marine Life Research Group	Marine Biology
Raymond W. Fitzgerald	Geological Research Division	X-ray Physics
Arthur O. Flechsig	Ocean Research Division	Biological Oceanography
Abraham Fleminger	Marine Life Research Division	Marine Biology
Theodore R. Folsom	Ocean Research Division	Physical Oceanography
Theodore D. Foster	Marine Physical Laboratory	Physical Oceanography
*Denis L. Fox	Marine Biology Research Division	Marine Biology
Jeffery D. Frautschy	Scientific Support Division	Marine Technology
Jane Z. Frazer	Geological Research Division	Numerical Analysis
Kurt A. I. Fredriksson	Geological Research Division	Mineralogy
Walter F. Garey	Physiological Research Laboratory	Physiology
Robert M. Garrels	Geological Research Division	Geology
Chris Garrett	Institute of Geophysics & Planetary Physics	Geophysics
Elizabeth L. Gealy	Deep Sea Drilling	Geology
Robert W. Gee	Marine Biology Research Division	Marine Toxology
Carl H. Gibson	AMES/Sea Grant Program	Fluid Dynamics
Joris M. T. M. Gieskes	Ocean Research Division	Marine Chemistry
J. Freeman Gilbert	Institute of Geophysics & Planetary Physics	Geophysics
Edward D. Goldberg	Geological Research Division	Chemistry
Fritz W. Goro	Marine Biology Research Division	Marine Biology
John J. Griffin	Geological Research Division	Mineralogy
Nicholas Grijalva	Ocean Research Division	Physical Oceanography
Roger Grismore	Ocean Research Division	Physical Oceanography

Name	Research Group	Field
Edwin L. Hamilton	Geological Research Division	Geophysics
Harold T. Hammel	Physiological Research Laboratory	Physiology
Douglas D. Hammond	Physiological Research Laboratory	Marine Physiology
Jeffrey S. Hanor	Geological Research Division	Mineralogy
James L. Harris	Visibility Laboratory	Optical Physics
Peter H. Hartline	Neurobiology Unit	Neurophysiology
Richard A. Haubrich	Institute of Geophysics & Planetary Physics	Geophysics
James W. Hawkins	Geological Research Division	Geology
Francis T. Haxo	Marine Biology Research Division	Marine Botany
Willis B. Hayes	Institute of Marine Resources	Ecology
Edvard A. Hemmingsen	Physiological Research Laboratory	Physiology
Myrl C. Hendershott	Ocean Research Division	Physical Oceanography
Maryanna Henkart	Neurobiology Unit	Neurophysiology
Robert R. Hessler	Marine Life Research Group/ Marine Biology Research Division	Biological Oceanography
Edmund S. Hobson	Department SIO	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
Hans-Willi Honegger	Sea Grant Program	Biology
Joseph C. Huang	Marine Life Research Group	Physical Oceanography
*Carl L. Hubbs	Marine Biology Research Division	Marine Biology
Kuni Hulsemann	Marine Life Research Group	Zooplankton Taxonomy
Frederick V. Hunt	Marine Physical Laboratory	Underwater Acoustics
Douglas L. Inman	Ocean Research Division	Physical Oceanography
John D. Isaacs	Institute of Marine Resources/ Marine Life Research Group	Oceanography
Marc Javoy	Geological Research Division	Geochemistry
*Martin W. Johnson	Marine Life Research Group	Marine Biology
James H. Jones	Ocean Research Division	Physical Oceanography
James Joseph	Institute of Marine Resources	Marine Biology
Joseph Wayne Joy	Advanced Ocean Engineering Laboratory	Oceanography
Adrianus J. Kalmijn	Neurobiology Unit	Neurophysiology
Daniel E. Karig	Geological Research Division	Marine Geology
Charles D. Keeling	Ocean Research Division	Marine Chemistry
+Juhee Kim	Marine Biology Research Division	Marine Microbiology
Helen K. Kirk	Marine Physical Laboratory	Marine Geophysics
Margaret D. Knight	Marine Life Research Group	Biological Oceanography
Minoru Koide	Geological Research Division	Marine Chemistry
Gerald L. Kooyman	Physiological Research Laboratory	Physiology
Ching-ming Kuo	Marine Biology Research Division	Biology
Devendra Lal	Geological Research Division	Nuclear Geophysics
G. David Lange	Neurobiology Unit	Neurophysiology
#Reuben Lasker	Department SIO	Marine Biology
+Francis T. LaQue	Sea Grant Program	Marine Corrosion
Richard F. Lee	Marine Biology Research Division	Biochemistry
David L. Leighton	Sea Grant Program	Marine Biology
Lanna Cheng Lewin	Marine Biology Research Division	Entomology
Ralph A. Lewin	Marine Biology Research Division	Marine Biology
Leonard N. Liebermann	Physics/Marine Physical Laboratory	Physics
Cinna Lomnitz	Geological Research Division	Geophysics
Alan R. Longhurst	Department SIO	Biological Oceanography
Carl D. Lowenstein	Marine Physical Laboratory	Marine Physics

#Adjunct Professor
*Emeritus
+Visiting



Dr. Edward L. Winterer teaches graduate class in sedimentary petrology.

Name	Research Group	Field
Sheina M. Marshall	Institute of Marine Resources	Marine Biology
Tetsuo Matsui	Marine Life Research Group	Biological Oceanography
Jerry L. Matthews	Geological Research Division	Geology
Edward D. McAlister	Marine Physical Laboratory	Physics
James J. McCarthy	Institute of Marine Resources	Biological Oceanography
Vance E. McClure	Sea Grant Program	Chemistry
*George F. McEwen	Ocean Research Division	Physical Oceanography
John A. McGowan	Marine Life Research Group	Biological Oceanography
Henry W. Menard	Geological Research Division/ Institute of Marine Resources	Geology
John W. Miles	AMES/Institute of Geophysics & Planetary Physics	Geophysics/Fluid Dynamics
Julian K. Miller	Marine Life Research Group	Biological Oceanography
Robert D. Moore	Institute of Geophysics & Planetary Physics	Geophysics
Gerald B. Morris	Marine Physical Laboratory	Geophysics
John D. Mudie	Marine Physical Laboratory/ Geological Research Division	Geophysics
Michael M. Mullin	Institute of Marine Resources	Biological Oceanography
Walter H. Munk	Institute of Geophysics & Planetary Physics	Geophysics
Lillian F. Musich	Deep Sea Drilling	Geology
Jerome Namias	Marine Life Research Group	Long-Range Weather Forecast/Ocean Atmosphere Interaction
Alasdair H. Neilson	Institute of Marine Resources	Biological Oceanography
Takahisa Nemoto	Marine Life Research Group	Marine Biology
Judd C. Nevenzel	Marine Biology Research Division	Biochemistry
William A. Newman	Scientific Support Division	Biological Oceanography
William A. Nierenberg	Director	Physics
William R. Normark	Geological Research Division	Geology
Takashi Okutani	Marine Life Research Group	Oceanography
Benton B. Owen	Marine Physical Laboratory	Chemistry
Frances L. Parker	Geological Research Division	Paleontology

Name	Research Group	Field
Robert L. Parker	Institute of Geophysics & Planetary Physics/Ocean Research Division	Geophysics
M. N. A. Peterson	Deep Sea Drilling/ Geological Research Division	Marine Geology
Richard P. Phillips	Geological Research Division	Geophysics
+Robert A. Phinney	Institute of Geophysics & Planetary Physics	Geophysics
Fred B Phleger	Geological Research Division	Oceanography
R. W. Piddington	Neurobiology Unit	Neurophysiology
Anthony C. Pimm	Deep Sea Drilling	Geology
William A. Prothero	Institute of Geophysics & Planetary Physics	Geophysics
Arthur D. Raff	Deep Sea Drilling	Marine Geophysics
Russell W. Raitt	Marine Physical Laboratory	Marine Geophysics
N. Solomon Raju	Marine Life Research Group	Marine Zoology
*Norris W. Rakestraw	Ocean Research Division	Marine Chemistry
Robert A. Rasmussen	Marine Physical Laboratory	Marine Physics
Stephen D. Rearwin	Marine Physical Laboratory	Physics
Archibald M. Reid	Geological Research Division	Mineralogy
Freda M. H. Reid	Institute of Marine Resources	Taxonomy
Joseph L. Reid	Marine Life Research Group/ Ocean Research Division	Physical Oceanography
+Francois J. Resch	Institute of Geophysics & Planetary Physics	Turbulence Measurements
*Roger R. Revelle	Director Emeritus	Marine Geology
Paul G. Richards	Institute of Geophysics & Planetary Physics	Geophysics
William R. Riedel	Scientific Support Division	Marine Geology
Margaret K. Robinson	Ocean Research Division	Physical Oceanography
Richard H. Rosenblatt	Marine Biology Research Division	Marine Zoology
Peter H. Roth	Deep Sea Drilling	Nannofossil Micro-paleontology
Philip Rudnick	Marine Physical Laboratory	Physics
Annika B. Sanfilippo	Geological Research Division	Paleontology
Marston C. Sargent	Scientific Support Division	Biological Oceanography
Milner B. Schaefer	Institute of Marine Resources	Biological Oceanography
Henning Scheich	Neurobiology Unit	Neurophysiology
Walter R. Schmitt	Marine Life Research Group	Marine Resources
Per F. Scholander	Physiological Research Laboratory	Marine Psysiology
Charles R. Schroeder	Marine Biology Research Division	Marine Biology
Richard A. Schwartzlose	Marine Life Research Group	Physical Oceanography
John G. Sclater	Marine Physical Laboratory	Geophysics
*Francis P. Shepard	Geological Research Division	Submarine Geology
George G. Shor	Geological Research Division/ Marine Physical Laboratory/ Sea Grant Program	Marine Geophysics
Maxwell Silverman	Scientific Support Division	Marine Engineering
John Sinkankas	Geological Research Division	Mineralogy
Raymond C. Smith	Visibility Laboratory	Physics
Stuart M. Smith	Geological Research Division	Submarine Geology
Frank E. Snodgrass	Institute of Geophysics & Planetary Physics	Geophysics
James M. Snodgrass	Scientific Support Division	Electronic Instrumentation
George N. Somero	Marine Biology Research Division	Marine Biology
Andrew Soutar	Marine Life Research Group	Paleontology
Fred N. Spiess	Marine Physical Laboratory	Marine Physics
Robert H. Stewart	Advanced Ocean Engineering Laboratory	Oceanography

#Adjunct Professor
*Emeritus
+Visiting

Name	Research Group	Field
John D. Strickland	Institute of Marine Resources	Biological Oceanography
Peter R. Supko	Deep Sea Drilling	Marine Geology
Bruce A. Taft	Marine Life Research Group	Physical Oceanography
John H. Taylor	Visibility Laboratory	Psychology
Judith Ann Tegger	Center for Marine Affairs	Science Policy
William H. Thomas	Institute of Marine Resources	Microbiology
Mizuki Tsuchiya	Institute of Marine Resources	Biological Oceanography
John E. Tyler	Visibility Laboratory	Physics
Victor Vacquier	Marine Physical Laboratory	Geophysics
Victor D. Vacquier	Marine Biology Research Division	Marine Biology
Tj H. van Andel	Geological Research Division	Oceanography
Charles W. Van Atta	AMES/Sea Grant Program	Geophysical Fluid Dynamics
William G. Van Dorn	Ocean Research Division	Physical Oceanography
Elizabeth L. Venrick	Marine Life Research Group	Biology
Benjamin E. Volcani	Marine Biology Research Division	Marine Microbiology
Christopher C. von der Borch	Deep Sea Drilling	Geology
Siegfried V. Wantrup	Institute of Marine Resources	Marine Economics
Ray F. Weiss	Geological Research Division	Geochemistry
Oscar E. Weser	Deep Sea Drilling	Marine Sedimentation
*Charles D. Wheelock	Institute of Marine Resources	Naval Architecture
Thomas W. Whitaker	Marine Biology Research Division	Marine Biology
Antony White	Marine Physical Laboratory	Geophysics
Warren B. White	Marine Life Research Group	Oceanography
Donald W. Wilkie	Aquarium-Museum	Marine Biology
Francis Williams	Institute of Marine Resources	Biological Oceanography
Peter M. Williams	Institute of Marine Resources	Biological Oceanography
+Mark H. Williamson	Department of SIO	Marine Ecology
Arnold Mark Wimbush	Institute of Geophysics & Planetary Physics	Geophysics
Edward L. Winterer	Geological Research Division	Geology
Jacqueline Mammerickx Winterer	Geological Research Division	Geology
Robert L. Wisner	Marine Biology Research Division	Marine Biology
Warren S. Wooster	Center for Marine Affairs/ Ocean Research Division	Physical Oceanography
Paula J. Worstell	Deep Sea Drilling	Geology
Max Wyss	Institute for Geophysics & Planetary Physics	Geophysics
A. A. Yayanos	Physiological Research Laboratory	Physiology
Claude E. ZoBell	Marine Biology Research Division	Marine Microbiology

Appendix A

DIRECTOR—DEAN
W. A. Nierenberg

ASSOCIATE DIRECTORS
G. G. Shor
F. N. Spiess

ASSISTANT DIRECTOR
J. D. Frautschy

INSTRUCTION

GRADUATE DEPARTMENT OF THE SCRIPPS INSTITUTION OF OCEANOGRAPHY
E. L. Winterer, Chairman
R. H. Rosenblatt, Vice Chairman

APPLIED OCEAN SCIENCES
Hugh Bradner

BIOLOGICAL OCEANOGRAPHY
J. T. Enright

GEOPHYSICS
J. F. Gilbert

MARINE BIOLOGY
R. A. Lewin

MARINE CHEMISTRY
C. D. Keeling

MARINE GEOLOGY
J. R. Curray

PHYSICAL OCEANOGRAPHY
C. S. Cox

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MARINE FACILITIES
P. G. Trapani

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MARINE BIOLOGY
A. A. Benson

OCEAN RESEARCH
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CENTER FOR MARINE AFFAIRS
W. S. Wooster, Director

DEEP SEA DRILLING
N. T. Edgar

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

ASSOCIATED RESEARCH

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

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

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W. J. Goff

PHOTOGRAPHIC LABORATORY
L. D. Ford

PUBLIC AFFAIRS
R. N. Fuller

Appendix B

SPONSORS OF RESEARCH AND GRADUATE INSTRUCTION

State:

Department of Fish and Game
Department of Water Resources

Federal:

Atomic Energy Commission
Environmental Protection Agency
  Water Quality Office
Executive Office of the President
  Central Intelligence Agency
National Aeronautics and Space Administration
National Science Foundation
Department of the Air Force
Department of the Army
Department of Commerce
  National Oceanic and Atmospheric Administration
    National Marine Fisheries Service
Department of Defense
  Advanced Research Projects Agency
  Defense Nuclear Agency
Department of Health, Education, and Welfare
Department of the Interior
  Fish and Wildlife Service
  Geological Survey
Department of the Navy
Department of Transportation
Public Health Service

Other:

American Cancer Institute
American Chemical Society
American Heart Association
American Optical Corporation
American Petroleum Institute
ARCS Foundation
Bear Creek Mining Company
Beckman Instruments, Inc.
Bendix Corporation
California Research Corporation
Chevron Oil Field Research Company
Commonwealth Fund Foundation
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Foundation for Ocean Research
General Dynamics
International Nickel Company
Jersey Production Research Company
Kennecott Copper Corporation
Kennecott Exploration, Inc.
Lockheed Missiles and Space Company
Marathon Oil Foundation
John B. McKee Fund
National Geographic Society
National Academy of Sciences
Nutrilite Products, Inc.
Ocean Science and Engineering, Inc.
Pan American Petroleum Foundation, Inc.
Peterson-Silberman Fund
Rockefeller Foundation
San Diego County Heart Association
E. B. Scripps Foundation
Francis P. Shepard Foundation
A. P. Sloan Foundation
Standard Oil Company of California
Scripps Industrial Associates
  Mobil Foundation, Inc.
  Texaco, Incorporated
  Occidental Petroleum Corporation
  Humble Oil Education Foundation
  Gulf Oil Corporation
  Sun Oil Company
  AMOCO Production Co.
Tenneco Oil Company
The Superior Oil Company
University Research Foundation
U. S. Steel Foundation
Van Camp Seafood Company
Westinghouse Corporation

Appendix C

MAJOR AWARDS AND HONORS

Dr. Denis L. Fox
Appointed to Distinguished Scholar Chair, Cranbrook Institute of Science, Bloomfield Hills, Michigan

Dr. William A. Nierenberg
Elected Member, National Academy of Sciences

Gene Hartlett, mechanician in Marine Sciences Development and Outfitting Shop, machines flange for a propeller shaft of R/V Melville.

Appendix D

RESEARCH VESSELS OF SCRIPPS INSTITUTION OF OCEANOGRAPHY

	Alexander Agassiz	Alpha Helix	Melville	Oconostota	Ellen B. Scripps	Thomas Washington	ST-908	FLIP
Type:	light freight	oceanographic research (biological)	oceanographic research	tug	off-shore supply	oceanographic research	harbor tug	floating instrument platform
Hull:	steel	steel	steel	steel	steel	steel	steel	steel
Year Built:	1944	1965-1966	1969	1944	1964-1965	1965	1945	1962
Year acquired: by SIO:	1961	1966	1969	1962	1965	1965	1961	1962
From whom acquired:	State Educational Agency for Surplus Property	National Science Foundation	U.S. Navy	U.S. Navy	Dantzler Boat and Barge Co.	U.S. Navy	U.S. Army	Gunderson Bros. Shipbuilding Co.
Owner:	University of California	University of California	U.S. Navy	U.S. Navy	University of California	U.S. Navy	University of California	U.S. Navy
Length:	180′	133′	245′	100	95′	209′	45′	355′
Beam:	32′	31′	46′	25′	24′	40′	12′5¾″	20/12′
Draft:	10′	10′5½″	15′	10′	6′	14′	5′1″	10′/300′
Displacement: tons (full):	869	512	1,915	327	115	1,362	28	2,100 (vertical)
Maximum speed:	11	12.3	12	11	9	12.5	9.5	varies[-1]
Minimum speed:	0–1	0.3	0–1	0–1	1	0–1	1	varies[-1]
Range (miles):	5,940	6,200	9,840	4,500	6,480	8,700	655	varies[-1]
Endurance (days):	22	30	41	16	30	29	4	varies[-1]
Crew:	18	12	25	8	5	25	2	5
Scientific party:	13	12	25	6	8	17	–	11

[-1] Depends on towing vessel
[-2] Including crew

1970–71 TOTAL DAYS AT SEA: 1,514
1970–71 NAUTICAL MILES STEAMED: 159,034

Appendix E

DOCTOR OF PHILOSOPHY DEGREES AWARDED IN 1970–71 WITH TITLES OF DISSERTATIONS

Earth Sciences

Ray F. Weiss, "Dissolved Gases and Total Inorganic Carbon in Seawater: Distribution, Solubilities, and Shipboard Gas Chromatography."

Peter M. Kroopnick, "Oxygen and Carbon in the Oceans and Atmosphere: Stable Isotopes as Tracers for Consumption, Production, and Circulation Models."

Marine Biology

James L. Congleton, "Response to Asphyxia of *Typhlogobius californiensis* Steindachner and some Related Gobies."

Jeffrey B. Graham, "Aspects of Temperature Sensitivity in Some Tropical Inshore Marine Fishes."

Richard F. Lee, "The Sulfoglycolytic Pathway in Plants and Algae."

Gerald W. Bowes, "Molecular Oceanography. I. DDT and Phytoplankton. II. DDE Action in Membrane Systems. III. Carbonic Anhydrase and CO_2 Transport."

Douglass F. Hoese, "A Revision of the Eastern Pacific Species of the Gobiid Fish Genus *Gobiosoma,* with a Discussion of the Relationships of the Genus."

William F. Blankley, "Auxotrophic and Heterotrophic Growth and Calcification of Coccolithophorids."

Alan R. Hargens, "Macromolecular Osmotic Pressures and Interstitial Fluid Pressures in Marine Multicellular Systems."

Mary R. Eaton, "Origin of the Resting Membrane Potential of the Moth Muscle Fiber."

Alfred R. Loeblich III, "The Physiology, Morphology and Cell Wall of the Marine Dinoflagellate *Cachonina niei.*"

Robert W. Piddington, "Central Control of Auditory Input in the Goldfish."

Oceanography

Clement G. Chase, "Tectonic History of the Fiji Plateau."

John B. Corliss, "Mid-Ocean Ridge Basalts: I-The Origin of Submarine Hydrothermal Solutions, II-Regional Diversity Along the Mid Atlantic Ridge."

John M. Edmond, "The Carbonic Acid System in Sea Water."

Jean M. Francheteau, "Paleomagnetism and Plate Tectonics."

Robert J. Tait, "Edge Wave Modes and Rip Current Spacing."

David R. Young, "The Distribution of Cesium, Rubidium, and Potassium in the Quasi-Marine Ecosystem of the Salton Sea."

Mary W. Silver, "Salp Swarms in the California Current."

James J. McCarthy, "The Role of the Urea in Marine Phytoplankton Ecology."

Michael C. Gregg, "Oceanic Microstructure."

MASTER OF SCIENCE DEGREES AWARDED IN 1970–71

Earth Sciences

Timothy P. Whorf

Marine Biology

James E. Smith

Oceanography

Eric R. Ernst
Wayne L. Olson
K. Gopalakrishnan
Robert T. Guza
Harold W. Lyons
Arnold J. Mantyla
Dwight D. Pollard
Alberto Ramirez-Flores
Hugh P. Slawson
Otto F. Steffin
Dennis D. Todd

Operating 24 hours a day, Scripps computers both at sea aboard research vessels and on land at the La Jolla campus collect and process data from oceanographic instrumentation.

Appendix F

REGENTS EX OFFICIO

Ronald Reagan
Governor of California and President of The Regents

Ed Reinecke
Lieutenant Governor of California

Robert Moretti
Speaker of the Assembly

Wilson Riles
State Superintendent of Public Instruction

Allan Grant
President of the State Board of Agriculture

Joseph A. Moore, Jr.
President of the Mechanics' Institute

Christian E. Markey, Jr.
President of the Alumni Association of the University of California

Charles J. Hitch
President of the University

APPOINTED REGENTS

Edwin W. Pauley
Edward W. Carter
Mrs. Randolph A. Hearst
John E. Canaday
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
Chairman of the Board
Robert O. Reynolds
Dean A. Watkins
John H. Lawrence, M.D.

REGENTS DESIGNATE

Bert L. Smith
Judge William B. Keene

PRINCIPAL OFFICERS OF THE REGENTS

Thomas J. Cunningham
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

John A. Perkins
Vice President—Administration

James B. Kendrick, Jr.
Vice President—Agricultural Sciences

Frank L. Kidner
Vice President—Educational Relations

Jay D. Michael
Vice President—Governmental Relations

Joseph W. McGuire
Vice President—Planning

David P. Gardner
Vice President—Public Service Programs and University Dean of University Extension

OFFICERS EMERITI

Robert Gordon Sproul
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

James H. Corley
Vice President—Governmental Relations and Projects, Emeritus

CHANCELLORS

Albert H. Bowker
Chancellor at Berkeley

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

Philip R. Lee
Chancellor at San Francisco

Vernon I. Cheadle
Chancellor at Santa Barbara

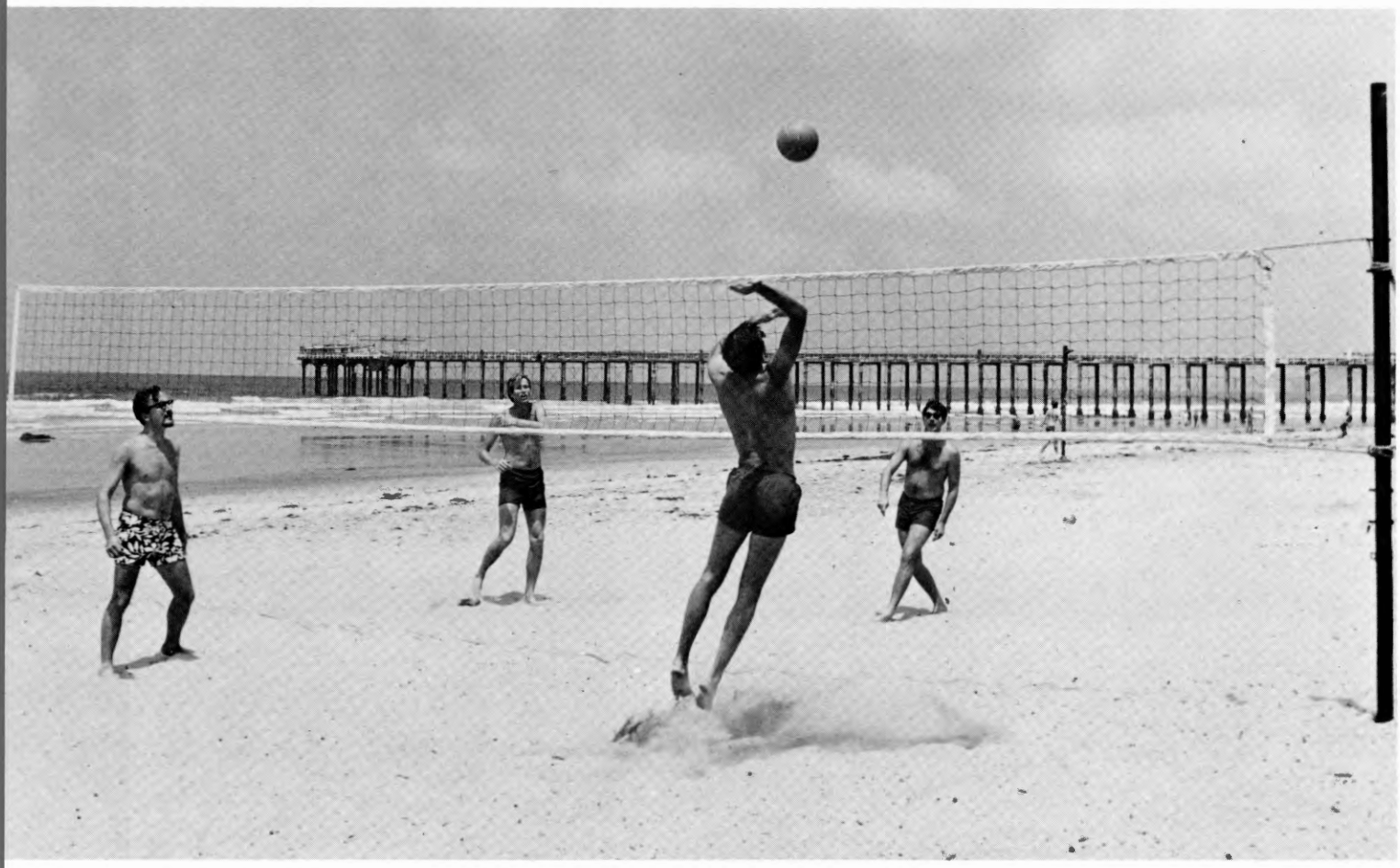
Dean E. McHenry
Chancellor at Santa Cruz

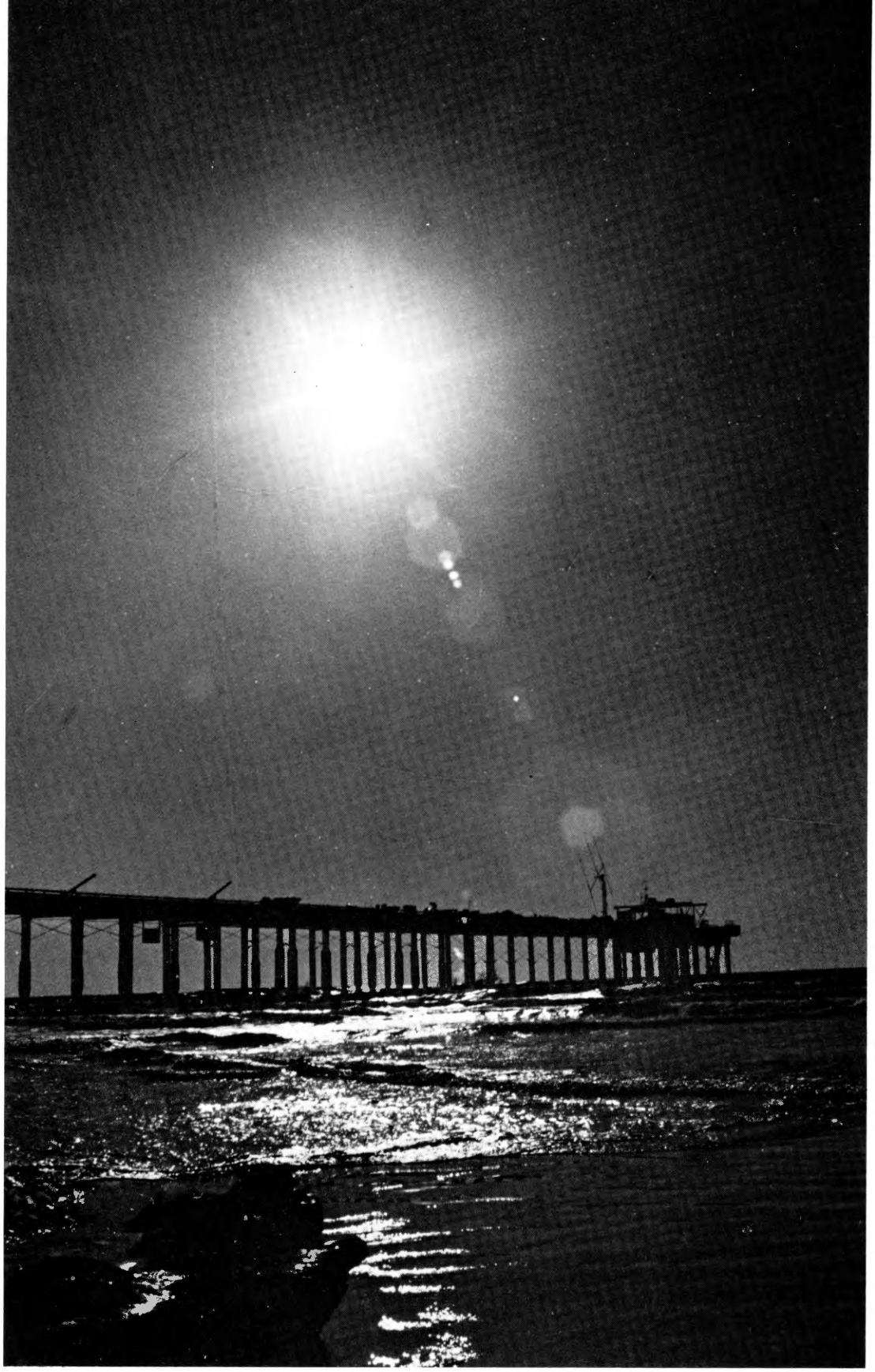
Appendix G

CURRENT EXPENDITURES BY MAJOR FUNCTION AND SOURCE
1970–71

Major Function	State of California Appropriations	Federal Contracts and Grants	Gifts, Endowments, and Other University Funds	Total Expense
Administration	$ 158,328	$ ——	$ 23,904	$ 182,232
Instruction and Departmental Research	469,126	66,410	65,020	600,556
Organized Research Divisions and Groups	1,504,345	15,433,898	218,162	17,156,405
Public Service	56,941	5,809	13,353	76,103
Scientific Support	831,072	2,740,623	75,231	3,646,926
Vaughan Aquarium-Museum Sales Desk	——	361	73,154	73,515
Total, SIO	3,019,812	18,247,101	468,824	21,735,737
Associated Research Institutes				
Institute of Geophysics and Planetary Physics				
Institute of Marine Resources	308,785	1,188,540	52,794	1,550,119
Total Marine Sciences Expenditures	$3,328,597	$19,435,641	$521,618	$23,285,856

NOTE: Includes direct costs only. Indirect costs covering general campus support services, etc., not shown.





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